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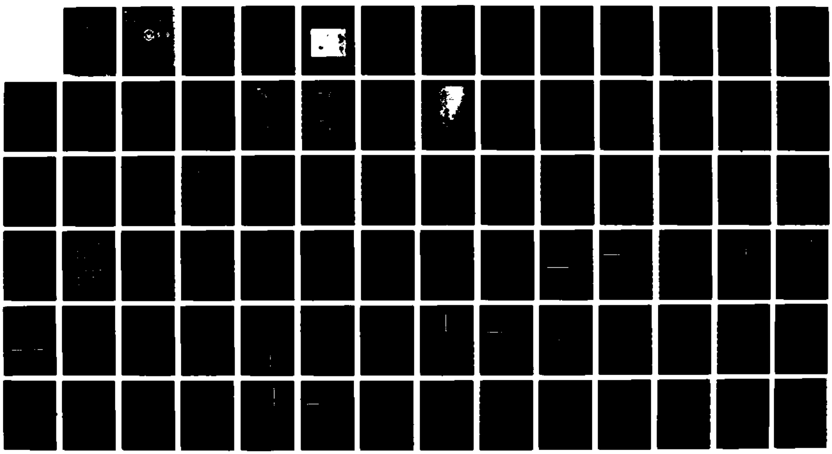

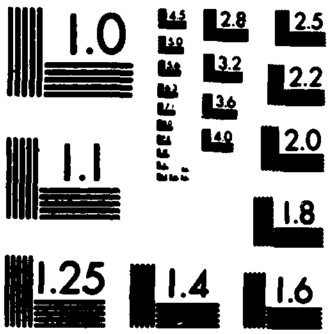
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NAVAL POSTGRADUATE SCHOOL

Monterey, California

OPPORTUNITIES FOR TROPICAL CYCLONE MOTION

RESEARCH IN THE NORTHWEST PACIFIC REGION

SCOTT A. SANDGATHE

AUGUST 1987

Interim Report for Period October 1986-September 1987

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Prepared for:
Chief of Naval Research (Code 1122MM)
Arlington, VA 22217

NAVAL POSTGRADUATE SCHOOL
Monterey, California

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Provost

The work reported herein was carried out by LCDR Scott A. Sandgathe (USN) while associated with the Tropical Cyclone Motion Studies research project that is funded by the Chief of Naval Research via the Marine Meteorology Section of the Office of Naval Research. Permission for LCDR Sandgathe to participate in the project was granted by CAPT O'Brien and CDR Tetrick of the USS Carl Vinson. LCDR Sandgathe's unique experience, especially as the former Deputy Director of the Joint Typhoon Warning Center in Guam, allowed him to prepare this summary of research needs in the Northwest Pacific region. This report will provide extremely useful guidance in planning tropical cyclone motion research studies.

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Tropical cyclone track prediction problems in the Northwest Pacific region that need to be researched are reviewed from the perspective of the operational forecaster. This information is provided as background for the upcoming Office of Naval Research field experiment on tropical cyclone motion. A short-term climatology of the frequency and spatial distribution of tropical cyclones is provided. Seven classes of operationally interested track forecast situations are described. Each cyclone from 1982 through 1985 is tabulated in terms of these classes.

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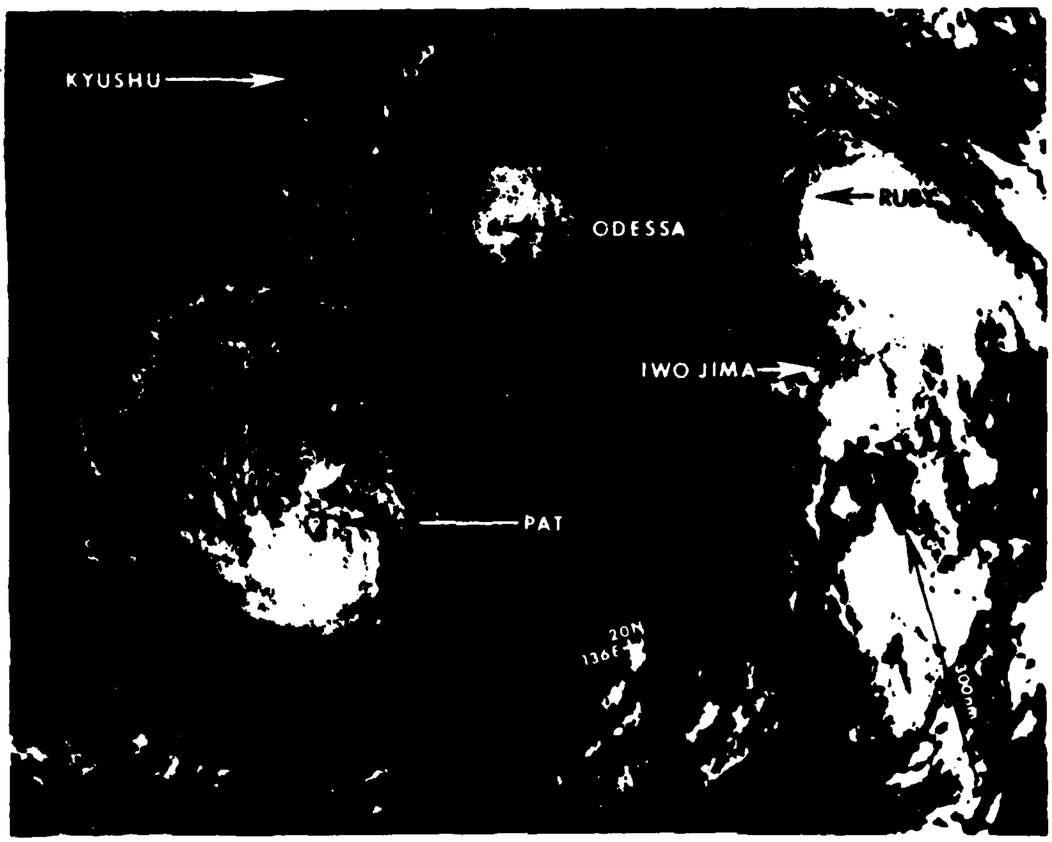

LCDR S. A. Sandgathe

August 1987

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ACKNOWLEDGEMENTS

There is a very urgent need for meaningful research on tropical cyclone motion in the Northwest Pacific. I am very grateful to Prof. Russ Elsberry of the Naval Postgraduate School and Dr. Bob Abbey of the Marine Meteorology Section of the Office of Naval Research (ONR) for inviting me to contribute to the planning for the ONR Field Experiment on Tropical Cyclone Motion. I also thank Capt O'Brien and Cdr Tetrick of the USS Carl Vinson for graciously giving me the opportunity. Several people who contributed information included in this paper deserve mention, most notably Dr. Ted Tsui of NEPRF and the staff at the Joint Typhoon Warning Center in Guam.

My participation in this project was funded through Prof. Elsberry's ONR contract (Program Element 611 53N; Project No. RR033-03-01) entitled "Tropical Cyclone Motion Studies."

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Fig. 14. Tropical cyclone interaction with Taiwan (from Wang, 1980).

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1. Introduction

This paper was written to provide background for the upcoming Office of Naval Research (ONR) field experiment on tropical cyclone motion. It provides a discussion of the forecast problem from an operational point of view and gives a physical description of the region in which the field experiment would be performed.

As presented at the July 1986 Planning Meeting on the Theory of Tropical Cyclone Motion (see Elsberry, 1986) held in Monterey, CA, a large amount of tropical cyclone research has been performed over the past four decades. Yet each season, forecasters in the Northwestern Pacific face forecast questions that have no clear answers. The theory of tropical cyclone motion has not presented them with the understanding of the complex interactions of a cyclone and its surrounding environment to the degree required for reliable forecasts. Current numerical and statistical forecast aids provide reasonable forecasts in the textbook forecast situations, yet common complications such as the presence of an adjacent tropical cyclone, extratropical transition or interaction with terrain often lead to large forecast errors. Errors on a few key typhoons provided strong operational motivation and support for the funding of the ONR research initiative on Tropical Cyclone Motion.

The Northwest Pacific is the planned site of the ONR field experiment.

This region is of high interest to the Department of Defense and is also adjacent to the most densely populated countries in the world. The geography, tropical cyclone climatology and weather observing network of the region are presented in Section 2 to familiarize readers with the region and to aid in the design of the field experiment.

Section 3 presents some of the more difficult track forecasting questions in the Northwest Pacific. These questions are presented from an operational rather than a theoretical point of view, with no attempt to identify the theoretical understanding that will be required to correctly handle the situation. Idealized examples are used to describe the forecast situations with references to recent Northwest Pacific tropical cyclones that exhibit these situations. Appendix A contains a list of sources that provide historical data for preliminary investigations and experimental design. Appendix B contains selected tropcial cyclone tracks from the Joint Typhoon Warning Center Annual Tropical Cyclone Reports. Tracks of all tropical cyclones referred to in Section 3 are included for quick reference.

2. NORTHWEST PACIFIC REGION

The Northwest Pacific region is the most active tropical cyclone region in the world. Tropical cyclones have occurred in every month of the year and as many as eight have occurred in a single month during the peak of the season. Although geographical features such as the South China Sea, Kuroshio Current and western Pacific High resemble the Gulf of Mexico, Gulf Stream and Bermuda High in the Northwest Atlantic, the similarity quickly ends. The greater tropical ocean area, mountainous islands and the monsoon climate of the Northwest Pacific region present a unique opportunity for tropical cyclone research as well as some unique problems. This section will describe the geography of the region, the tropical cyclone climatology and current weather observing network.

a. Geography

The Northwest Pacific region (Fig. 1) includes the western North Pacific Ocean, the Philippine Sea, the South China Sea, the East China Sea, the Yellow Sea and the Sea of Japan. These large bodies of water are loosely separated by several major island chains that form a complete ring around the Philippine Sea, which is where the vast majority of all Northwest Pacific cyclones form. These island chains provide sites for a unique observing network, but also add to the forecast difficulties of the region. Several of the major islands (e.g., the Philippines, Taiwan, Japan and also the Korean peninsula) are very mountainous with coastal mountains of 6000 to 10,000 ft and peaks as high as 13,000 ft.

Distances between major cities or DOD bases are also presented in Fig. 1. These sites would be the most suitable locations from which to

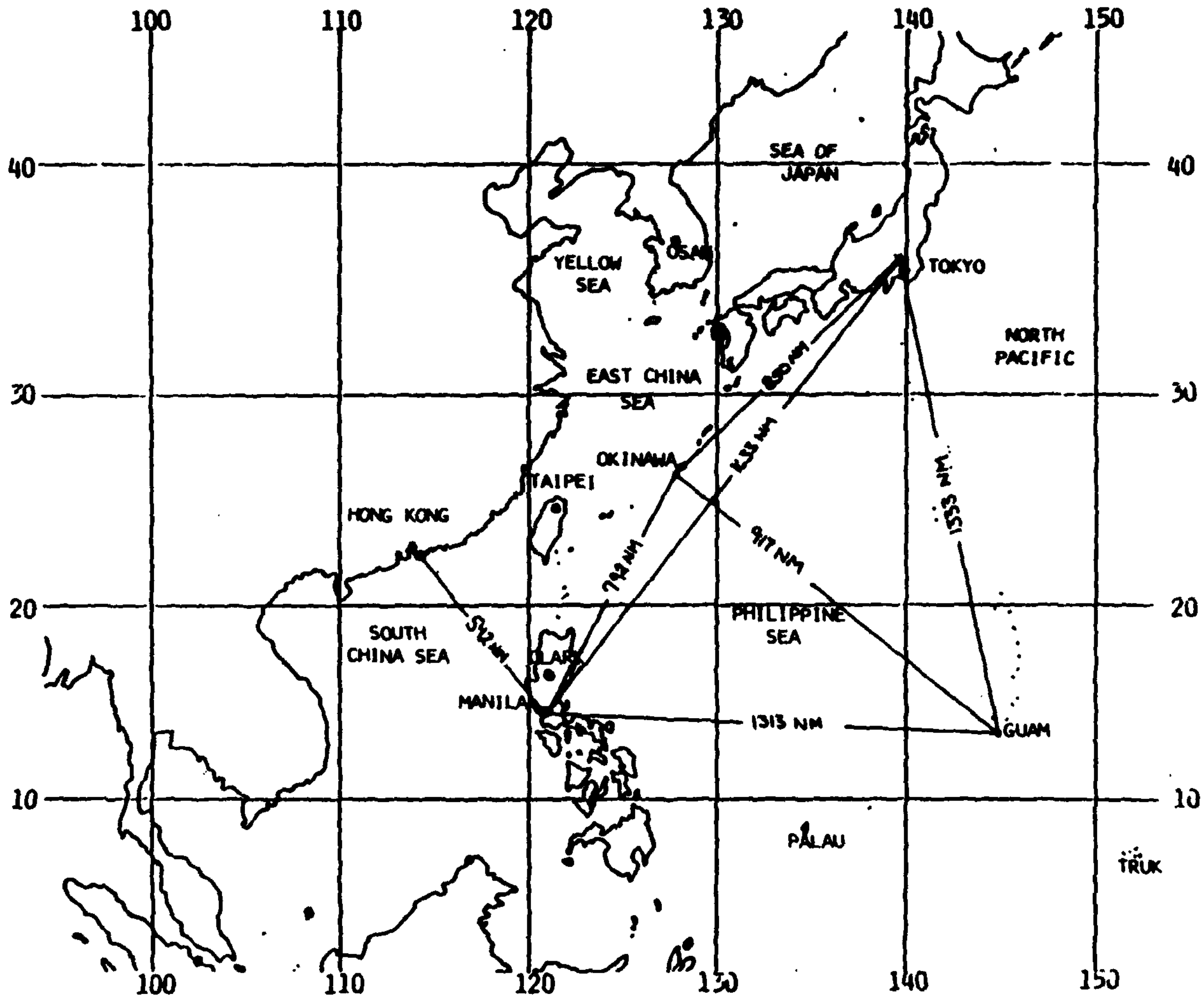

Fig. 1. The Northwest Pacific Region with distances between key locations.

operate weather reconnaissance aircraft, although several alternative sites are available among the major islands in the region.

b. Tropical cyclone climatology

The typhoon occurrence frequency by month and year for the last 26 years is presented in Table 1. If tropical cyclones that did not achieve typhoon intensity are included, the average number per year increases to over 27. As mentioned earlier, typhoons may occur in any month of the year in the Northwest Pacific, with the peak frequency of over three per month occurring in August, September and October. Note also that there has only been one season in 26 years where no typhoons occurred during a peak season month. Although September 1960 had only three tropical storms, eight typhoons occurred during the preceeding month and four during the following month. If an experiment was planned for any two-month period from August through November, the lowest expected number of typhoons would be two and the average expectancy almost five.

Shifts in the geographical distributions are shown by the average number of tropical cyclones that pass through five deg lat by five deg lon areas for each month from July through December (Fig. 2). The maximum cyclone occurrence in any month is in the western Philippine Sea, and shifts north toward Okinawa during August and September. This maximum occurrence also shifts slightly from season to season in response to planetary wave positions.

Composite cyclone tracks from 1984 and 1985 are included in Figs. 3 through 6 to help the reader visualize some typical cyclone tracks in the region. The type of cyclone track varies during the season,

Table 1. Frequency of typhoons occurring in the Northwest Pacific region by month from 1959 to 1985.

FREQUENCY OF TYPHOONS BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1959	0	0	0	1	0	0	1	5	3	3	2	2	17
1960	0	0	0	1	0	2	2	8	0	4	1	1	19
1961	0	0	1	0	2	1	3	3	5	3	1	1	20
1962	0	0	0	1	2	0	5	7	2	4	3	0	24
1963	0	0	0	1	1	2	3	3	3	4	0	2	19
1964	0	0	0	0	2	2	6	3	5	3	4	1	26
1965	1	0	0	1	2	2	4	3	5	2	1	0	21
1966	0	0	0	1	2	1	3	6	4	2	0	1	20
1967	0	0	1	1	0	1	3	4	4	3	3	0	20
1968	0	0	0	1	1	1	1	4	3	5	4	0	20
1969	1	0	0	1	0	0	2	3	2	3	1	0	13
1970	0	1	0	0	0	1	0	4	2	3	1	0	12
1971	0	0	0	3	1	2	6	3	5	3	1	0	24
1972	1	0	0	0	1	1	4	4	3	4	2	2	22
1973	0	0	0	0	0	0	4	2	2	4	0	0	12
1974	0	0	0	0	1	2	1	2	3	4	2	0	15
1975	1	0	0	0	0	0	1	3	4	3	2	0	14
1976	1	0	0	1	2	2	2	1	4	1	1	0	15
1977	0	0	0	0	0	0	3	0	2	3	2	1	11
1978	0	0	0	1	0	0	3	2	4	3	2	0	15
1979	1	0	1	1	0	0	2	2	3	2	1	1	14
1980	0	0	0	0	2	0	3	2	5	2	1	0	15
1981	0	0	1	0	0	2	2	2	4	1	2	2	16
1982	0	0	2	0	1	1	2	5	3	3	1	1	19
1983	0	0	0	0	0	0	3	2	1	4	2	0	12
1984	0	0	0	0	0	0	4	2	1	5	3	1	16
1985	0	0	0	0	1	2	1	5	3	4	0	1	17
AVERAGE	.2	.04	.2	.6	.8	.9	2.7	3.3	3.1	3.1	1.6	.6	17.3

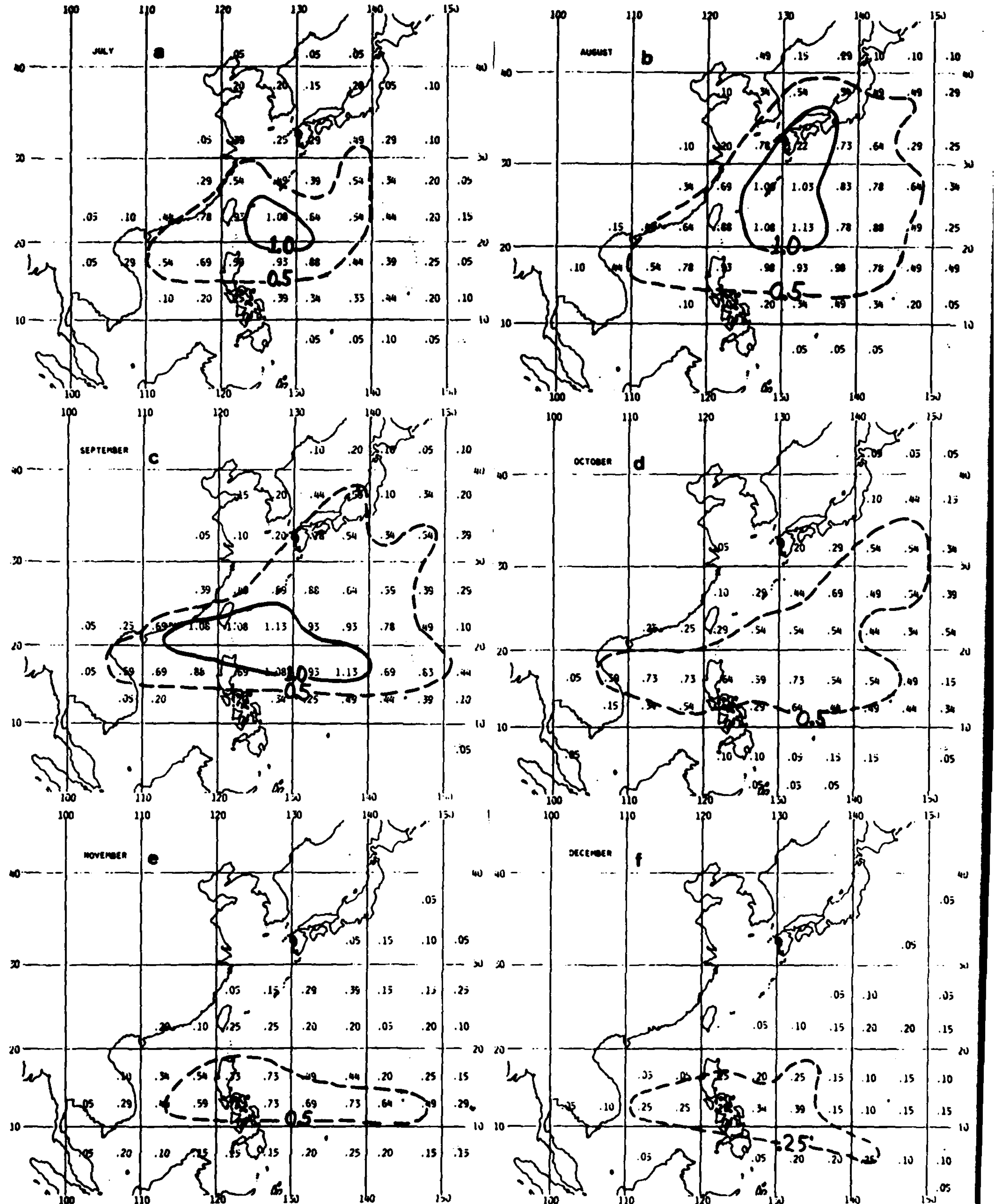

Fig. 2. The average number of tropical cyclones passing through a five deg lat by five deg lon square by month for the Northwest Pacific region for (a) July, (b) August, (c) September, (d) October, (e) November, and (f) December.

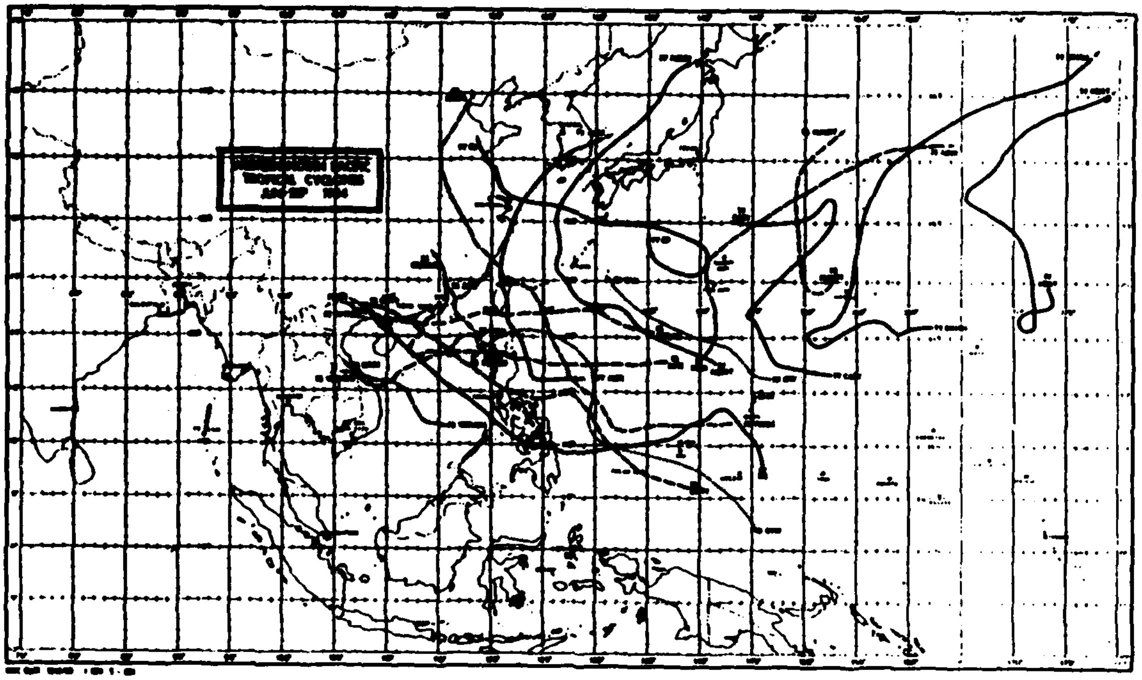

Fig. 3. Northwest Pacific tropical cyclone tracks for June through September 1984.

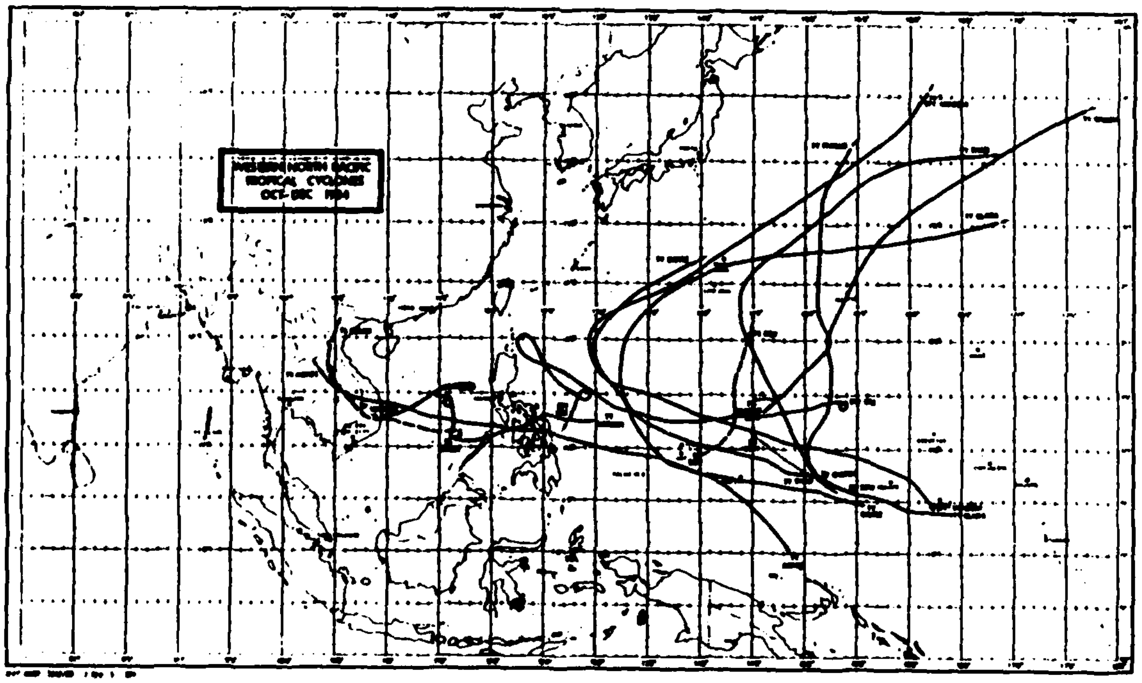

Fig. 4. As in Fig. 3 for October through December 1984.

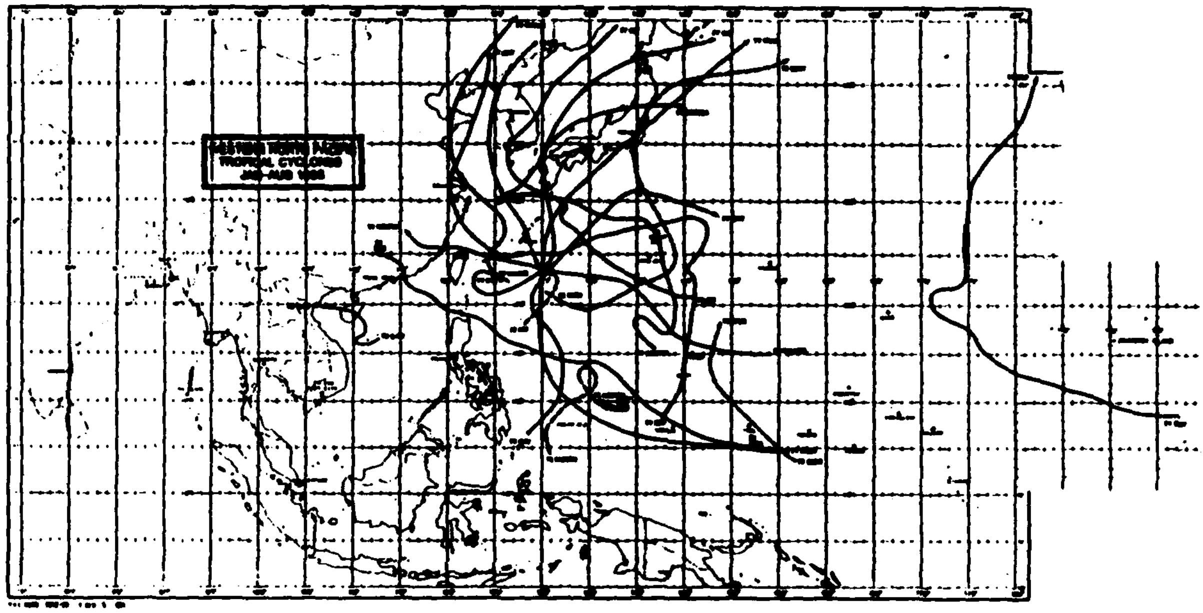

Fig. 5. As in Fig. 3 for January through August 1985.

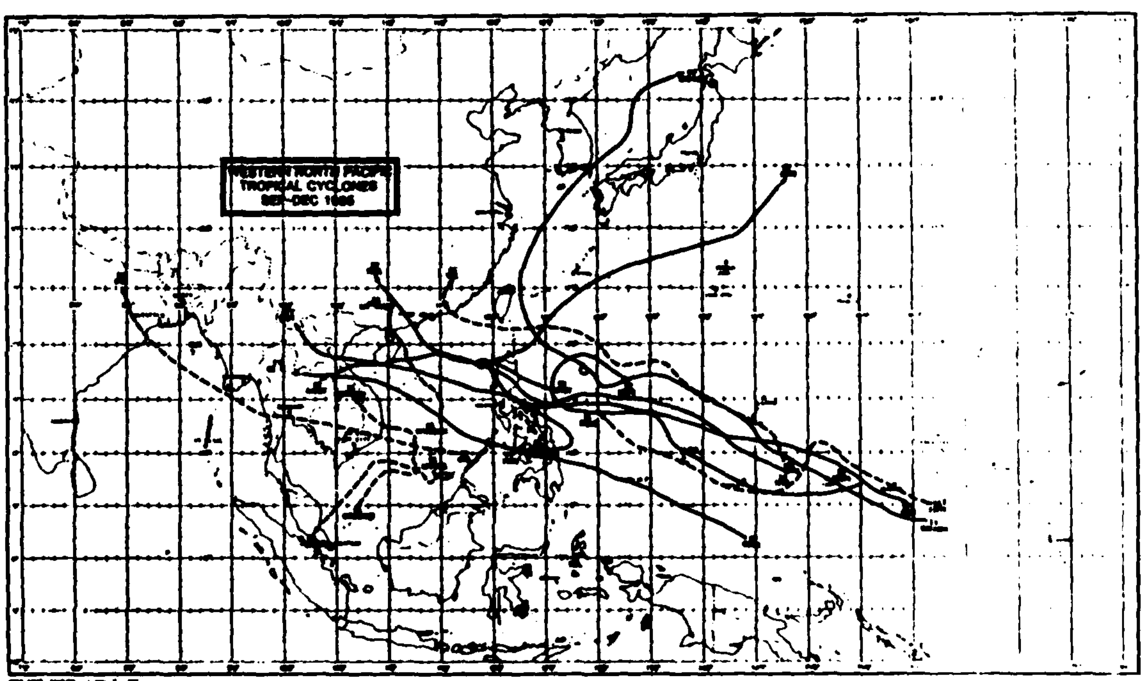

Fig. 6. As in Fig. 3 for September through December 1985.

with more straight tracks (under the subtropical ridge) or classic recurvature tracks (around the subtropical ridge) during the later part of the season.

c. Observing network

Weather observing stations in the tropics have always been scarce and the Northwest Pacific region is no exception, although it has more reporting stations than most tropical regions. Coverage along the Asian coast and in the major islands is excellent and the many islands in the region offer numerous sites for remote observing stations.

An example of current surface weather observation coverage in the region is given in Fig. 7. Land observing stations and routine ship observations give adequate large-scale coverage of all areas except the Philippine Sea between 15^{0} and 25^{0} N. In this area, ocean buoys or additional ship observations would be required to provide adequate coverage for most experiments.

Upper-air coverage (Fig. 8) is adequate along the coast of Asia and in the major islands. Many stations in the Philippine Sea, particularly in the Caroline Islands, have been closed since the early 1970's due to funding constraints and political changes. Other stations in this region only report once each 24 h. This reqion would require additional upper-air coverage for many motion experiments.

Military and commercial aircraft reports supplement the rawinsonde network. Additional military pireps may be available on a time-delayed basis which would not compromise military aircraft positions during operational missions. The 54th Weather Reconnaissance Squadron, which

Fig. 7. Surface synoptic weather reporting stations for 0000 UTC 16 June 87.

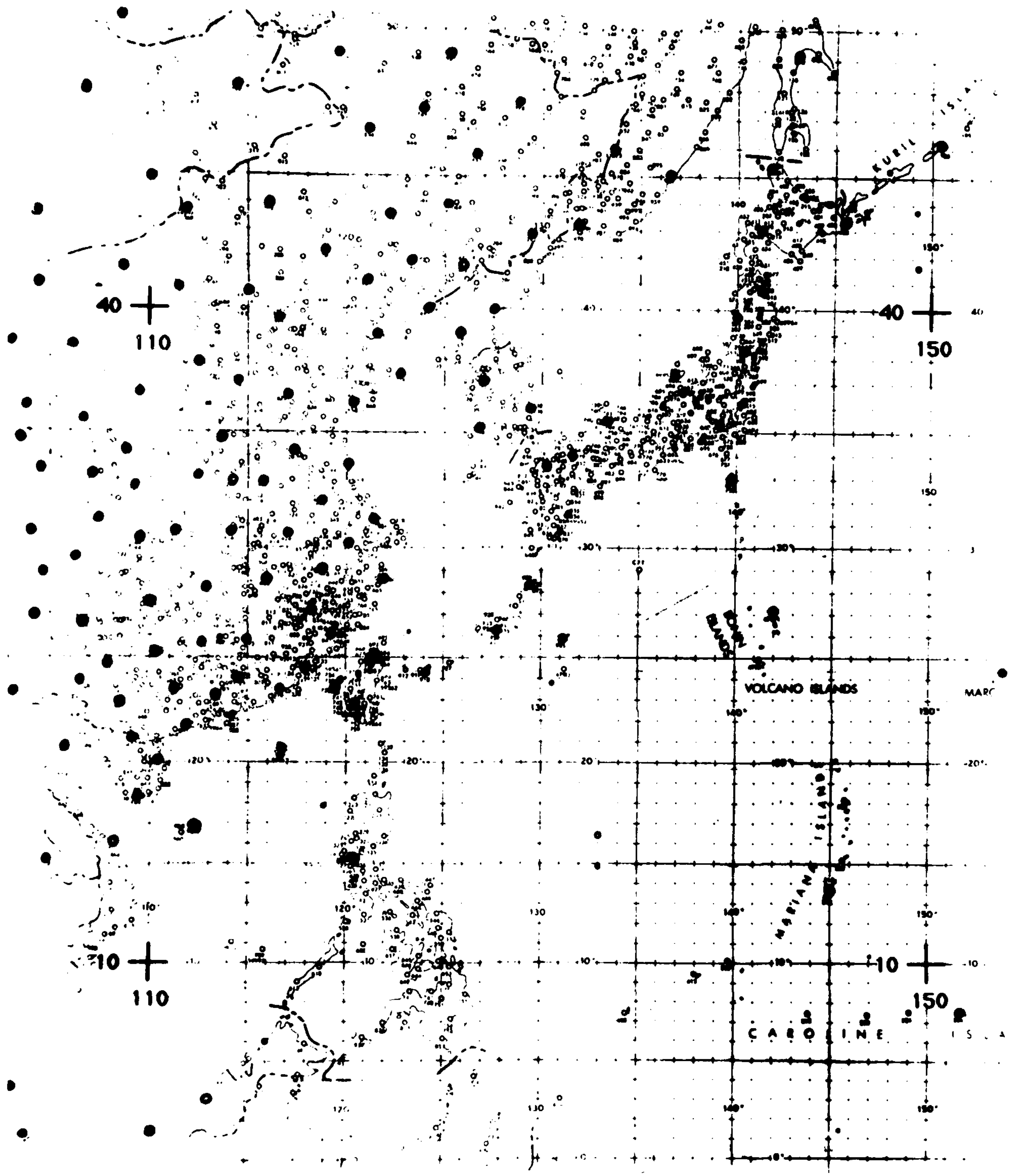

Fig. 8. Rawinsonde and pirep reporting locations for 1200 UTC 15 June 87 and 0000 UTC 16 June 87.

normally performs typhoon reconnaissance in the Northwest Pacific, is scheduled to be disestablished on 1 October 1987. Other Air Force weather reconnaissance aircraft fly in the region but do not perform typhoon reconnaissance missions.

Radar coverage is available for all DOD bases and major population centers. Figure 9 was taken from the Typhoon Operation Experiment (Topex) Operational Manual and is a display of current radar coverage with the exception of Xisha Dao in the Paracel Islands (WMO 59981), which is not a normal reporting station. Guam is not shown in Fig. 9 but it is also a reliable reporting station. (China has recently received some additional radars but these may not be available at the time of the field experiment). Although some radar stations in the Philippines have had problems with reliability, the U.S. radars there are very reliable.

Satellite coverage in the region is provided by the NOAA and DMSP polar orbiting satellites and the Japanese GMS geostationary satellite, which is located at 140°E.

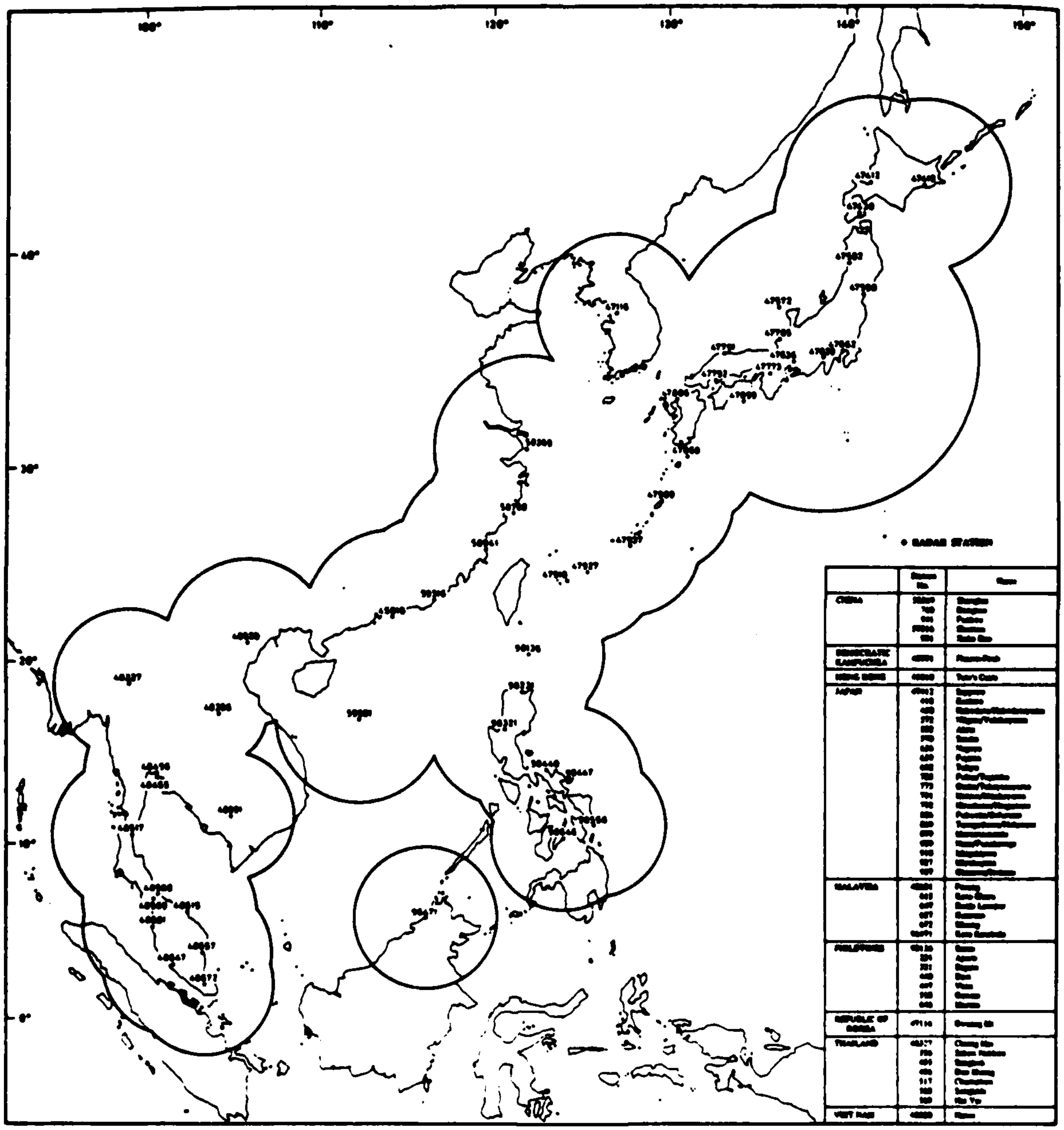

Fig. 9. Northwest Pacific Region weather radar sites during the Typhoon Operation Experiment (TOPEX).

3. FORECAST PROBLEMS

a. Selection process

The selection of tropical cyclones as "operationally interesting cases" for further study is necessarily a very subjective process. Every cyclone seems to exhibit special track characteristics, and some are more easily forecast than others. Even a cyclone that moves consistently on a straight path may pose difficult forecast problems. These forecast problems are not always evident when the entire track evolution is viewed after the fact, because an in-depth knowledge is required of what actually occurred "in the pits" as the forecasts were formulated.

Not all difficult forecasts are scientifically interesting cases. Many forecasts fail from inaccurate initial conditions, lack of synoptic data, inaccurate cyclone positioning or improper analysis. These cases, as well as cases that occur so infrequently that there is little chance of a reoccurrence during a field experiment, have not been included in this discussion.

The cases selected are situations that confront the forecaster each season, and which continue to pose difficult forecast problems. Selection is not for "scientific merit" but for their impact on the tropical cyclone forecast problem in the Northwest Pacific. These are the cases that I would like to fully understand as a forecaster.

The frequency and the seasonal distribution of interesting cases during the Northwest Pacific tropical cyclone season are displayed in Table 2. The cases are arranged in order of decreasing impact on overall forecast skill. Stated differently, forecast skill in the first case would

Table 2. Operationally interesting tropical cyclone forecast cases in the Northwest Pacific region from 1982 to 1985.

CASES	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
CYCLONE - CYCLONE INTERACTION	-	1	5	2	1	2	-	11
CYCLONE - MIDLATITUDE TROUGH INTERACTION	2	9	11	7	10	5	2	46
CYCLONE - SUBTROPICAL RIDGE INTERACTION	2	5	6	3	1	-	-	17
EXTRATROPICAL TRANSITION	3	3	6	6	6	1	1	26
TERRAIN INTERACTION	2	8	9	8	5	2	2	36
MONSOON SURGE INTERACTION	3	-	6	2	3	4	6	24
TUTT OR UPPER LOW INTERACTION	1	4	5	3	5	-	-	18
TOTAL TYPHOON/TS 1982 - 1985	8	13	22	16	20	10	6	95

eliminate the greatest number of large track forecast errors (e.g., forecasts that failed to provide adequate warning due to direction errors of greater than 45 deg or speed errors resulting in timing errors of more than 12 h).

Cyclones were assigned to categories based on the definitions given below. A cyclone could qualify for more than one category if it exhibited the requisite characteristics. Two subjective factors that affected the categorization need to be emphasized. First, only cases that posed interesting forecast difficulties were included. Thus, a cyclone that tracked cleanly around the subtropical ridge was not tabulated as a subtropical ridge interaction. Secondly, it was difficult to identify the "negative" cases -- cyclones that were expected to have interactions, but the interactions never occurred. This is a serious shortcoming, as these cases are just as important to the forecaster as those cases in which interaction actually occurs.

Northwest Pacific tropical cyclones from 1982 through 1985 are listed in Tables 3 to 6. The forecast characteristics of each cyclone are tabulated in more detail and the tables also indicate time of occurrence and if the overall horizontal dimensions (size) of the cyclone contributed to the forecast difficulty. These tables are intended to allow the reader to refer to specific examples of forecast situations and will be presented in greater detail in the case descriptions below.

b. Case description

(1) Multiple cyclone interaction. The interaction of two or more tropical cyclones is one of the most challenging track forecast questions a forecaster must face. As demonstrated in Table 2, this occurs an average

STORM NAME	START MONTH	SIZE	DUAL STORM	MIDLAT TROF STEP	MIDLAT TROF LOOP	RECURVE	SUBTROP RIDGE EXTEND	SUBTROP RIDGE THRU	SUBTROP RIDGE ODD	TERRAIN	EXTRATRP TRANSITN	MONSOON SW	MONSOON NE	TUTT/UPPR LOW PRESENT	TUTT/UPPR LOW TRACK
TS MAMIE	MAR									Y					
TY NELSON	MAR+									Y					
TY ODESSA	MAR+			Y	Y										
TY PAT	MAY					Y	Y				Y				
TY RUBY	JUN					Y					Y	Y			
TS TESS	JUN+											Y			
TS SKIP	JUN+										Y				
TS VAL	JUL										Y				
TS WINONA	JUL						Y			Y					
TY ANDY	JUL				Y					Y				Y	
STY BESS	JUL+			Y	Y		Y			Y					
TY CECIL	AUG			?	?				Y						
TY DOT	AUG						Y		Y	Y				Y	
TY ELLIS	AUG							Y		Y	Y				
TY FAYE	AUG+	SM			Y					Y		Y			
TY GORDON	AUG+			Y		Y	Y				Y			Y	
TS HOPE	SEP														
TY IRVING	SEP						Y			Y					
TY JUDY	SEP					Y		Y		Y	Y			Y	
TY KEN	SEP	SM						?		Y	Y				
TS LOLA	SEP					Y					Y			Y	
STY MAC	OCT					Y					Y				
TY NANCY	OCT						Y			Y				Y	
TY OWEN	OCT					Y									Y
TY PAMELA	NOV+			Y	Y					Y					
TY ROGER	DEC									Y			Y		

Table 3. Occurrence of interesting forecast situations during 1982 in the Northwest Pacific Region.

STORM NAME	START MONTH	SIZE	DUAL STORM	MIDLAT TROF STEP	MIDLAT TROF LOOP	MIDLAT TROF RECURVE	SUBTROP RIDGE EXTEND	SUBTROP RIDGE THRU	SUBTROP RIDGE ODD	TERRAIN	EXTRATRP TRANSITN	MONSOON SW	MONSOON NE	TUTT/UPPR LOW PRESENT	TUTT/UPPR LOW TRACK
TS SARAH	JUN														
TY TIP	JUL									Y					
TY VERA	JUL						Y			Y				Y	
STY WAYNE	JUL									Y				Y	
STY ABBY	AUG	LG	I		Y	Y		Y		Y	Y				
TS BEN	AUG		I												
TS CARMEN	AUG		I												
TS DOM	AUG					Y						Y			
TY ELLEN	AUG+									Y				Y	
STY FORREST	SEP			Y		Y				Y	Y				
TS GEORGIA	SEP+														
TS HERBERT	OCT														
TY IDA	OCT	SM				Y					Y			Y	
TY JOE	OCT									Y					
TS KIM	OCT									Y					
TY LEX	OCT			Y	Y										
STY MARGE	OCT+			Y		Y					Y				
TS NORRIS	NOV	SM									Y				
TY ORCHID	NOV		I										Y		
TY PERCY	NOV		I									Y			
TS RUTH	NOV				Y								Y		
TS SPERRY	DEC												Y		
TS THELMA	DEC					Y							Y		

Table 4. As in Table 3 for 1983.

STORM NAME	START MONTH	SIZE	DUAL STORM	MIDLAT TROF			SUBTROP RIDGE			TERRAIN	EXTRATRP TRANSITN	MONSOON		TUTT/UPPR LOW	
				STEP	LOOP	RECURVE	EXTEND	THRU	ODD			SW	NE	PRESENT	TRACK
TS VERNON	JUN														
TS WYNNE	JUN								Y	Y					
TY ALEX	JUL					Y				Y	Y				
TS BETTY	JUL														
TY CARY	JUL			Y					Y					Y	
TY DINAH	JUL+		I			Y			Y		Y				
TY ED	JUL+		I		Y										
TS FREDA	AUG									Y					
TS GERALD	AUG											Y			
TY HOLLY	AUG	LG				Y				Y	Y	Y			
TY IKE	AUG+	SM	I				Y			Y					
TS JUNE	AUG	LG	I							Y		Y			
TY KELLEY	SEP					Y									Y
TS LYNN	SEP														
TS MAURY	SEP+		I									Y			
TS NINA	SEP+		I								Y	Y			
TY OGDEN	OCT										Y				
TY PHYLLIS	OCT										Y				
TS ROY	OCT														
TS SUSAN	OCT														
TY THAD	OCT					Y								Y	
STY VANESSA	OCT		I			Y					Y				
TY WARREN	OCT		I									Y			
TY AGNES	NOV									Y					
STY BILL	NOV	SM	I		Y								Y		
TY CLARA	NOV	LG	I			Y									
TY DOYLE	DEC					Y									

Table 5. As in Table 3 for 1984.

STORM NAME	START MONTH	SIZE	DUAL STORM	MIDLAT TROF			SUBTROP RIDGE			TERRAIN	EXTRATRP TRANSITN	MONSOON		TUTT/UPPR LOW	
				STEP	LOOP	RECURVE	EXTEND	THRU	ODD			SW	NE	PRESENT	TRACK
TS ELSIE	JAN											Y			
TS FABIAN	JAN											Y			
TY GAY	MAY	SM									Y			Y	
TY HAL	JUN	LG					Y			Y		Y		Y	
TY IRMA	JUN+					Y					Y				
TY JEFF	JUL+			Y		Y				Y					
TY KIT	AUG	LG		Y		Y					Y				
TS LEE	AUG														
TY MAMIE	AUG									Y					
TY NELSON	AUG									Y				Y	
TY ODESSA	AUG+	SM													
TY PAT	AUG+	LG									Y				
TS RUBY	AUG+														
TY SKIP	AUG+			Y		Y									
TY TESS	SEP									Y					
TS VAL	SEP									Y					
TS WINONA	SEP														
TY ANDY	SEP+									Y					
TY BRENDA	SEP+				Y	Y				Y	Y				
TY CECIL	OCT									Y					
STY DOT	OCT									Y					
TS ELLIS	OCT														Y
TY FAYE	OCT+				Y							Y			
TS GORDON	NOV												Y		
TY HOPE	DEC									Y	Y		Y		
TS IRVING	DEC												Y		

Table 6. As in Table 3 for 1985.

of three times per season (11 cases in four years) in the Northwest Pacific. Very little guidance is available to the forecaster except papers describing the "Fujiwhara effect" which has not been applied operationally. All of the statistical or climatological techniques for track guidance are heavily biased toward single cyclones and the operational numerical models cannot handle multiple cyclones.

In this case, multiple-cyclone interacion is taken to include all forms of cyclone-cyclone interaction, rather than just the classic Fujiwhara motion. One of the most common forms of interaction in the Northwest Pacific occurs when one cyclone enhances the monsoon flow surrounding the second cyclone. A schematic showing the mid-level flow surrounding the two cyclones in this case is shown in Fig. 10a. The cyclone embedded in the monsoon flow tends to move with the flow while the other cyclone controls the depth and strength of the monsoon flow. Typhoons (TY) Orchid and Percy in 1983 and Super Typhoon (STY) Vanessa and TY Warren in 1984 are excellent examples of a typhoon embedded in the Southwest Monsoon that is influenced by an adjacent typhoon. Also in 1984, STY Bill was interacting with the Northeast Monsoon flow when TY Clara appeared to enhance the flow and cause Bill to "shear" and move southeast.

Another form of interaction is the apparent building of a ridge between the two cyclones that appears to force the cyclones apart. Typical tracks of the two cyclones are depicted in Fig. 10b. The cyclones are initially drawn toward each other as in a Fujiwhara interaction, but then a narrow ridge appears to force the cyclones apart. There have been no studies to date to verify if the ridge is a result of cyclone-cyclone interaction or if it is an unrelated synoptic event. Typhoons Cecil and Dot

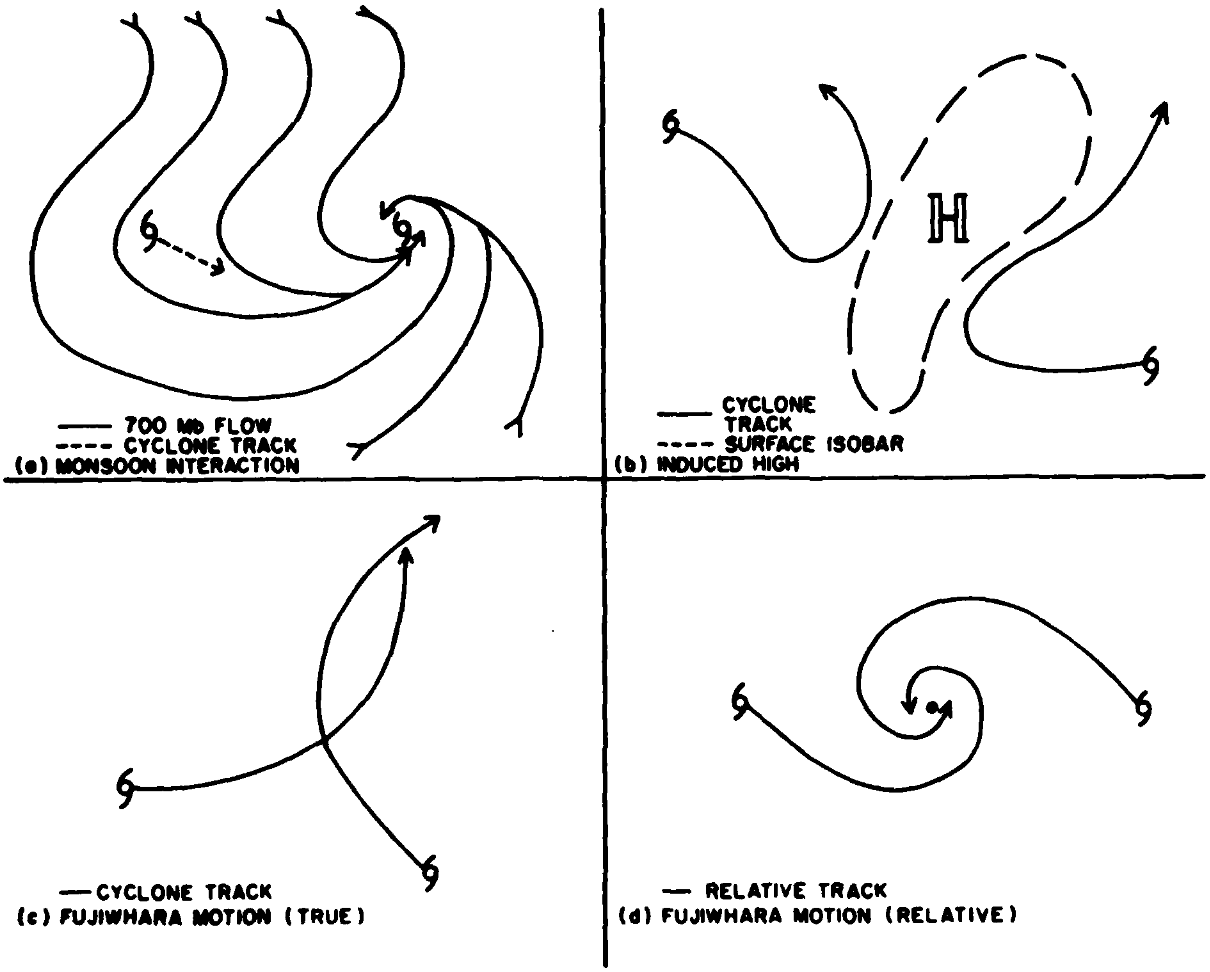

Fig. 10. Tropical cyclone motion during cyclone - cyclone interaction for (a) monsoon interaction, (b) induced surface high pressure, (c) true Fujiwhara motion, and (d) Fujiwhara motion relative to the "center" of the cyclone pair.

in 1982 and Dinah and Ed in 1984 are cases in which this interaction is suspected to be responsible for unusual cyclone motion.

A third interaction occurs when the outflow from one cyclone inhibits the development and therefore the structure of the second cyclone, and indirectly changes its response to environmental steering and the final track. This interaction occurs frequently whenever multiple cyclones exist and has led to a general forecasting rule that cyclones with a separation of less than 15 deg lat will tend to inhibit development of both cyclones while a separation of greater than 15 deg lat may actually enhance development through enhanced outflow. The motion interaction results from the cyclone responding to a shallower steering flow when its convection is suppressed than when strong convective development is present.

The final form of multiple-cyclone interaction is the classic Fujiwhara effect. Although no forecast technique to predict Fujiwhara motion is in use, possible recent examples of this motion are Typhoons Maury and Nina in 1984 and Odessa and Pat in 1985. This motion has been described as the rotation of two cyclones about their "center of mass" while the combined cyclones follow the environmental steering. Schematics of an idealized Fujiwhara interaction with both the true motion and the motion relative to the center point between the two cyclones are shown in Figs. 10c and 10d.

(2) <u>Cyclone</u> - <u>midlatitude</u> <u>trough</u> <u>interaction</u>. The interaction of a cyclone and a midlatitude trough results in a recurvature/no-recurvature forecast; i.e. will the cyclone be picked up by the trough and accelerated rapidly off to the northeast (Fig. 11a) or will it continue slowly westward

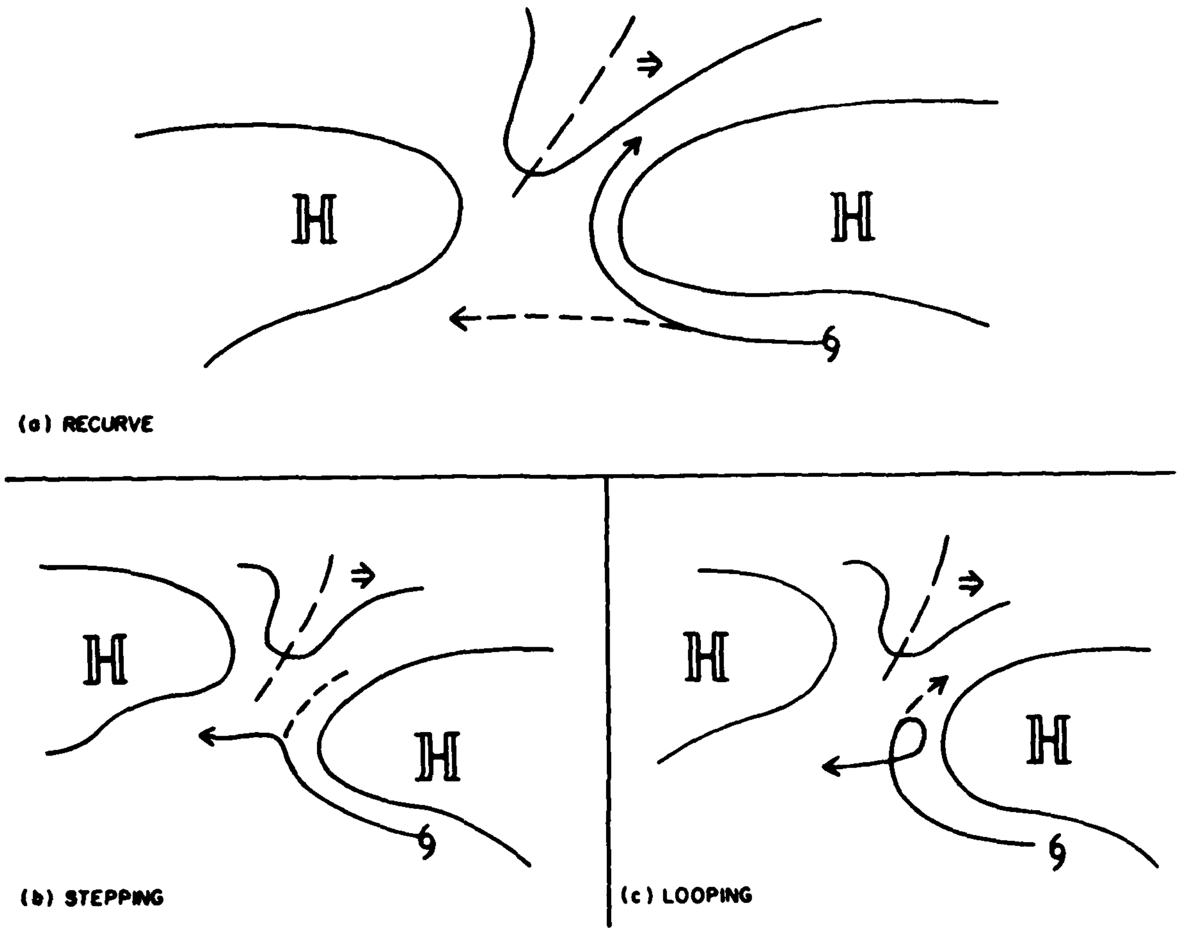

Fig. 11. Tropical cyclone motion during cyclone - midlatitude trough interaction for (a) recurvature, (b) stepping and (c) looping.

(or even south of west). Almost every year, incorrect recurvature forecasts result in 72 h track forecast errors of over 1000 n mi. Since approximately half of all Northwest Pacific tropical cyclones eventually do recurve, this recurvature forecast question is faced frequently by operational forecasters.

If the track of the cyclone was significantly affected by the passage of a mid-latitude trough, then the cyclone was included as one of the cases in Table 2. In Tables 3 to 6, this category is further subdivided into "step", "loop" and "recurve".

Stepping (Fig. 11b) occurs when a passing mid-latitude trough weakens the subtropical ridge and the steering flow surrounding the tropical cyclone. The translation speed of the cyclone then decreases and it moves on a more poleward track. As the trough passes, the subtropical ridge is reestablished and the tropical cyclone resumes its westward movement. Thus, the resulting cyclone track appears to step northward with each passing trough. TY Gordon in 1982 and STY Marge in 1983 are excellent examples of stepping.

Looping (Fig. 11c) occurs under the same circumstances as stepping, although the tropical cyclone actually moves eastward before resuming its westward motion. TY Lex in 1983 and TY Brenda in 1985 are recent examples of cyclones looping.

Both of these scenarios result in 12 to 24 h track "feints" toward the north that often lead to erroneous recurvature forecasts. Tropical cyclones labeled as "recurve" are those cyclones that eventually complete recurvature, tracking north of the subtropical ridge and accelerating to the northeast. Stepping and looping tropical cyclones often eventually

recurve and thus a cyclone may be listed under more than one of these categories.

There are numerous statistical, empirical, climatological and numerical methods for forecasting recurvature. These often fail in the near-miss situations of stepping or looping as the techniques can not resolve the crucial difference between recurvature and non-recurvature. The importance of the recurvature forecast to the overall cyclone motion forecast cannot be overstated, because this is where the largest motion errors occur. A better understanding of the physical processes involved and more reliable forecast techniques are required.

(3) Cyclone-subtropical ridge interaction. Nearly all Northwest Pacific tropical cyclones interact with the subtropical ridge during their existence. In most cases, these are the easiest systems to forecast as the cyclone track tends to parallel the height contours of the ridge and move at fairly persistent speeds (see Fig. 12a). However, some cyclones fail to move smoothly around the ridge, and exhibit motion that does not agree with predictions of forecast aids or available descriptions of cyclone-ridge interaction. The occurrences of these unexplained interactions are documented in Table 2.

The unusual cyclone-ridge motion cases have been further separated into "extend", "thru" and "odd" categories in Tables 3 to 6. Cases defined as "extend" have the ridge building or extending westward (Fig. 12b) which causes the cyclone to remain on a more westward course. It has been hypothesized in several Annual Tropical Cyclone Reports, as in the case of TY Vera in 1983, that interaction with the cyclone may actually cause the ridge to build westward in these cases and thus result in a

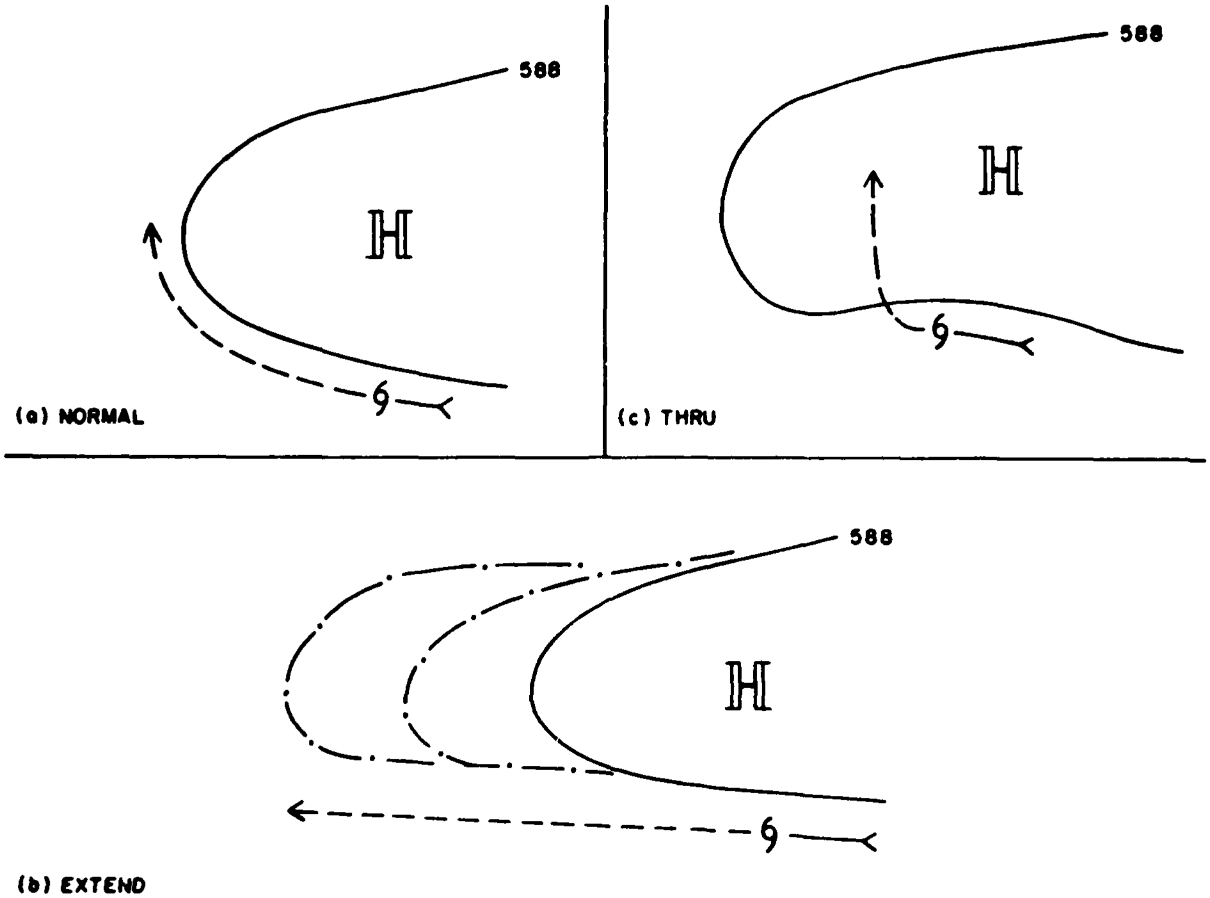

Fig. 12. Tropical cyclone motion during cyclone - subtropical ridge interaction for (a) normal motion, (b) extending ridge and (c) through ridge.

nonlinear steering effect.

Cyclone cases defined as "thru" are those in which the cyclone unexpectedly moves through an apparently well-established subtropical ridge. This is shown schematically in Fig. 12c and an infamous recent case of this is STY Abby in 1983. Those remaining cases in which the cyclone motion is apparently the result of subtropical ridge interaction, but are not easily categorized, have been grouped together as "odd".

(4) Extratropical transition. Extratropical transition occurs as a tropical cyclone is transformed from a warm core system to a hybrid or cold-core system. During the transition process, radical track and speed changes frequently occur. The movement of the cyclone is also dependent on the nature or type of the transition and the ultimate structure of the transitioned system.

Shimamura (1985) reviews several ways a recurving tropical cyclone moving into the midlatitudes may transition into an extratropical system. First, a complex transition occurs when the tropical cyclone merges with a pre-existing front or baroclinic zone and a new extratropical wave is formed along the front (see TY Clara during 1984 for a recent example of a complex transition). Second, a compound transition occurs when the tropical cyclone merges with a pre-existing extratropical low to form a single system (e.g., STY Bess, 1982). Third, the tropical cyclone may interact with a strong upper-level trough without a low-level baroclinic zone, develop its own low-level baroclinic zone and transition to a strong extratropical low (Shimamura's strong interaction). Fourth, the tropical cyclone may interact with an upper-level trough but slowly weaken and become a very shallow system that does not develop strong baroclinic

instability (Shimamura's weak interaction).

Each of these transition processes has its own unique tropical-cyclone track characteristics. A strong interaction generally results in a sudden acceleration and a more northward track as the upper-level trough strengthens in response to the tropical cyclone, which is followed 18 to 36 h later with a significant deceleration as the cyclone completes extratropical transition (see Fig. 13a and TY Holly, 1984). A weak interaction results in a speed consistent with the upper-level flow and a more eastward track (see Fig. 13b and STY Mac, 1982). TY Owen (1982) is an excellent example of how the tropical cyclone track may be dominated by the transition process (Fig. 13c). TY Owen commences a weak-interaction transition and turns eastward. It then transitions into a subtropical cyclone and then becomes a tropical system again, with rapid deceleration and a southeastward movement. After 48 h, it again commences extratropical transition and reaccelerates to the northeast.

Current numerical models are unable to simulate correctly the variety of complex structures that occur in transitioning cyclones and therefore fail to accurately predict the associated track changes. Statistical and climatological models tend to average out the details of the transition phase, and thus do not forecast the associated motion changes. As Shimamura emphasizes, the damage associated with a transitioning tropical cyclone can be very significant and more knowledge of the transition process and its effect on cyclone motion is required.

(5) Terrain interaction. The Northwest Pacific has several major islands that have terrrain reaching elevations of 6,000 to 13,000 ft. Interaction with these islands can cause motion deviations that are very

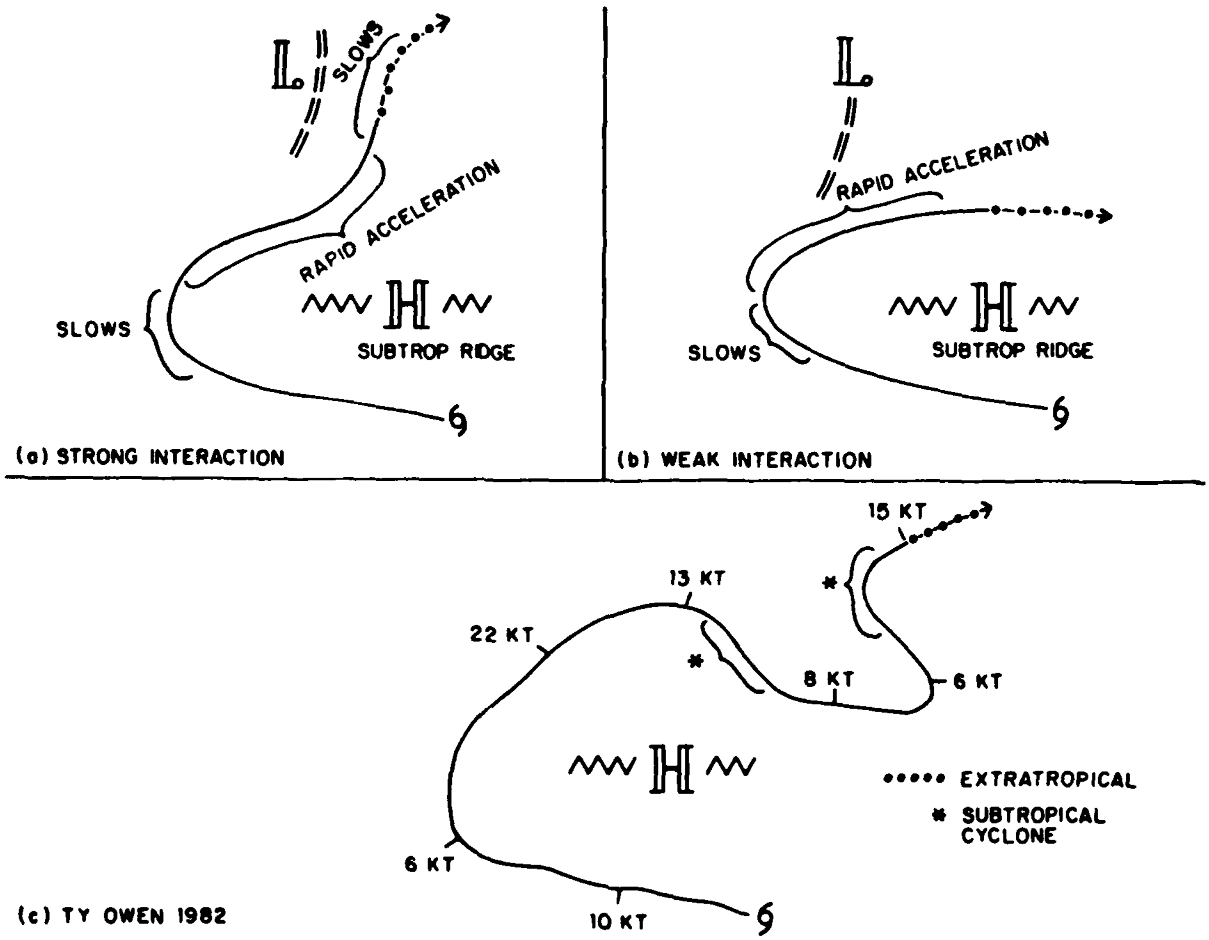

Fig. 13. Tropical cyclone motion during extratropical transition for (a) strong interaction, (b) weak interaction and (c) TY Owen (1982) multiple transitions.

difficult to forecast. Empirical studies such as Brand and Blelloch (1973) reveal unexplained accelerations and decelerations as the cyclone approaches land as well as preferred tracks across land.

The variety of ways a tropical cyclone can interact with mountainous terrain is readily evident by examining Fig. 14 from Wang (1980). Tropical cyclone speed is not indicated in the figure so the complexity of the problem is understated somewhat. Typhoons Alex and Ike from 1984 are recent examples of terrain interaction with both speed and track changes (as well as intensity and maximum wind radii changes). In Tables 2 to 6, only those cyclones that remain at least tropical storm intensity after interacting with a major island are included. This number is still one third of the total tropical cyclones occurring in the region.

These sudden track and speed changes at the crucial moment when evacuations and preparations are taking place has a very significant impact on the effectiveness of the forecasts and warnings in often highly populated areas.

(6) Monsoon surge interaction. The Northeast and Southwest Monsoons along the Asian continent have a significant impact on tropical cyclone motion. Cyclones forming within the Southwest Monsoon trough in the South China Sea and Philippine Sea are often nearly stationary and appear to move only in response to fluctuations in the intensity of the monsoon. These cyclones generally intensify to 55 to 75 kt while embedded in the monsoon trough. They also frequently exhibit diurnal track changes in response to diurnal changes in the intensity of the monsoon. Typhoon Percy in 1983, and TY Warren and TS Gerald in 1984 are examples of cyclones that remained nearly stationary in the monsoon .

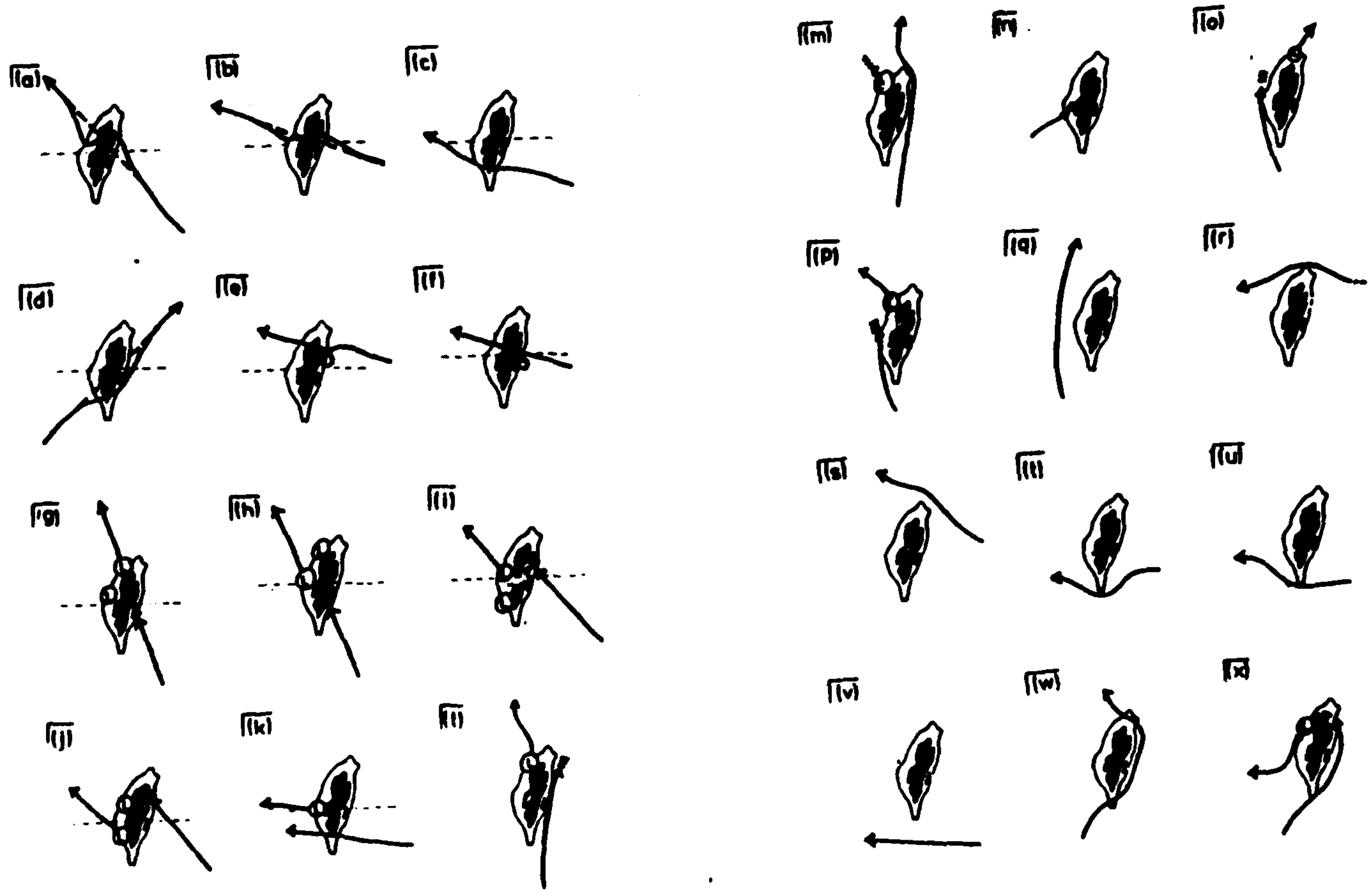

Fig. 14. Tropical cyclone interaction with Taiwan (from Wang, 1980).

trough for several days. TS Gerald also demonstrated diurnal fluctuations, with an apparent northward component of motion occurring during the day and a southward component during the night.

Many late season cyclones moving into the northern Philippine Sea often move erratically for periods up to several days in response to surges in the Northeast Monsoon coming off the Asian continent. These cyclones are generally caught between a westerly flow at upper levels and a northeasterly flow at low levels. The resulting motion is extremely difficult to forecast. Typhoon Orchid and Tropical Storms Ruth, Sperry and Thelma from 1983 are a series of tropical cyclones interacting with the Northeast Monsoon, which exhibit the possible types of motion including quasi-stationary, southwest, southeast and delayed recurvature to the northeast.

Cyclone - monsoon interaction is not properly handled by current forecast aids. Numerical models will often give an indication when the interaction should occur, but they are not capable of forecasting the resulting track and structure changes. Statistical and climatological aids similarly indicate a slower motion, but rarely provide reliable track forecasts.

(7) TUTT or upper low interaction. Although a large amount of research has been published on the effect of upper low systems on the intensity of tropical cyclones, little has been written concerning their influence on the cyclone track. Roughly one fifth of the Northwest Pacific cyclones interact with upper lows, and occasionally the interaction results in a significant (and usually unforecast) effect on the cyclone motion. These track interactions can result in very unusual cyclone

motion such as south or southeastward movement (see TY Ellis in 1985) or very sudden track accelerations. Unfortunately, these interactions are almost always identified after they occur. No help is available from numerical or statistical forecast techniques.

All cases of cyclone with a TUTT/upper low in close proximity have been included in Table 2 because of the difficulty of determining the impact of the upper low on the cyclone's motion. It should be mentioned that upper-level low systems are often analyzed incorrectly or missed entirely due to the resolution of upper-level observations over the tropical ocean areas, which contributes significantly to the forecast problem.

4. References

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Wang, S. T., 1980: Prediction of the behavior and strength of typhoons in Taiwan and its vicinity. **Research Report 18, National Science Council (NSC-67M-0202-0501),** Taipei, Taiwan, 100 pp.

APPENDIX A

DATA SOURCES

National Climatic Data Center
National Environmental Satellite, Data and Information Service
Federal Building
Asheville, NC 28801

National Snow and Ice Data Center
CIRES Campus Box 449
University of Colorado
Boulder, CO 80309-0449

Department of Meteorology
Naval Postgraduate School
Monterey, CA 93943-5000

Naval Environmental Prediction Research Facility
Monterey, CA 93943-5006

Naval Oceanography Command Center/Joint Typhoon Warning Center
COMNAVMAR, Box 12
FPO, San Francisco, 96630

NOAA/NESDIS/NCC
Satellite Data Services Division
World Weather Building, Room 100
Washington, DC 20233-1000.

Department of Meteorology-HIG331
University of Hawaii
2525 Correa Road
Honolulu, HA 96822

Department of Meteorology
Colorado State University
Ft Collins, CO 80523

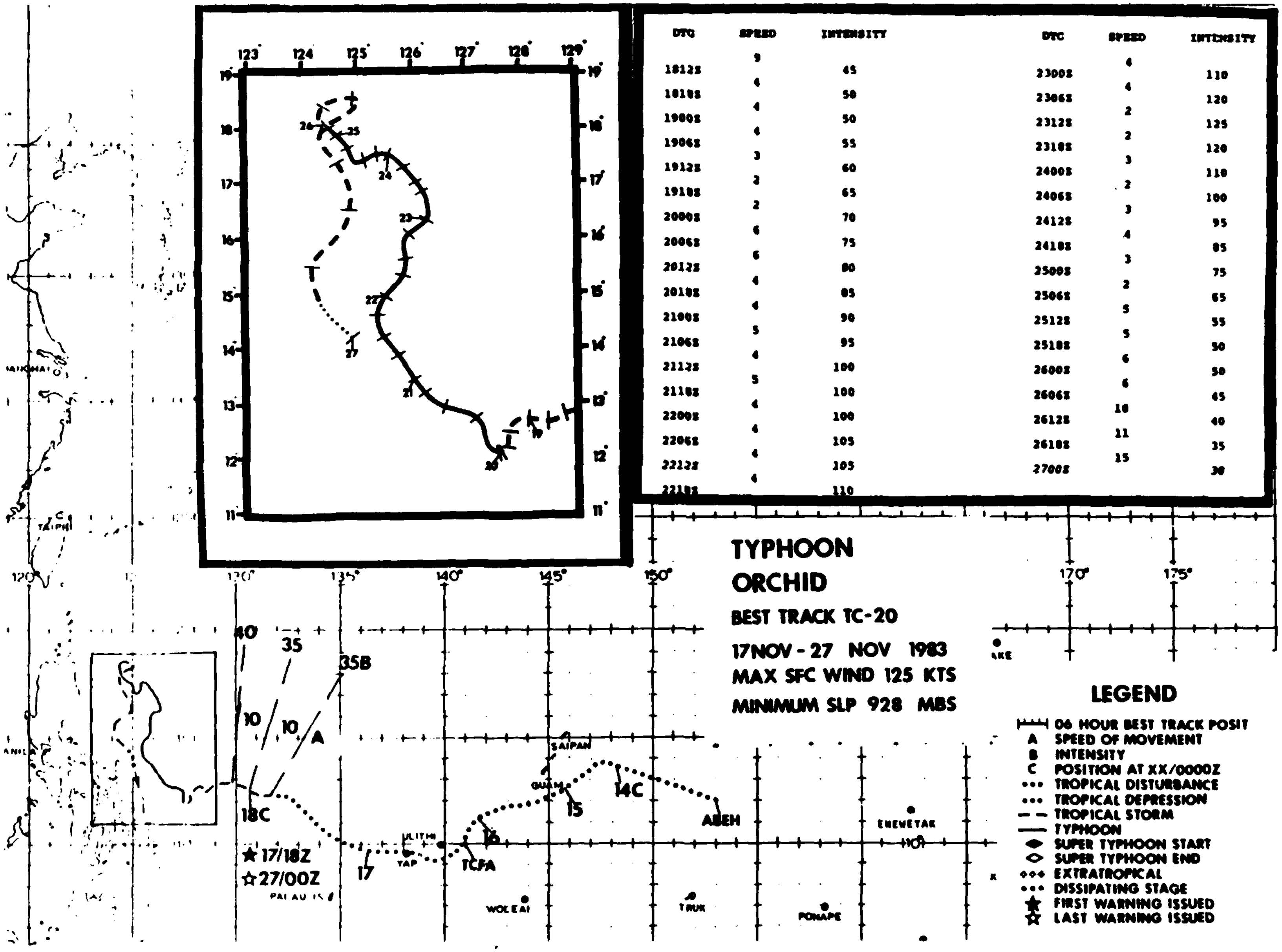
Headquarters,
Japan Meteorological Agency
Otemachi 1-3-4, Chiyodaku
Tokyo, Japan 100

APPENDIX B

SELECTED TROPICAL CYCLONE TRACKS

The following tropical cyclone tracks were referred to in the case descriptions in section 3 and are included to help the reader visualize the cyclone motion. The figures have been taken from the 1982 to 1985 Joint Typhoon Warning Center Annual Tropical Cyclone Reports. The annual reports also contain a complete history of the tropical cyclones and describe some of the interesting forecast events.

STORM NAME	YEAR	OPERATIONALLY INTERESTING FEATURE(S)	PAGE
Orchid	1983	Storm Interaction plus NE Monsoon	B-3
Percy	1983	Storm Interaction plus SW Monsoon	B-4
Vanessa	1984	Storm Interaction	B-5
Warren	1984	Storm Interaction plus SW Monsoon	B-6
Bill	1984	Storm Interaction	B-7
Clara	1984	Storm Interaction plus Midlatitude Trough	B-9
Cecil	1982	Storm Interaction	B-10
Dot	1982	Storm Interaction	B-11
Dinah	1984	Storm Interaction	B-12
Ed	1984	Storm Interaction	B-13
Gordon	1982	Stepping	B-14
Marge	1983	Stepping	B-15
Lex	1983	Looping	B-16
Brenda	1985	Looping	B-17
Vera	1983	Ridge Effect	B-18
Abby	1983	Ridge Effect	B-19
Bess	1982	Midlatitude Trough	B-20
Holly	1984	Midlatitude Trough	B-21
Owen	1982	Midlatitude Trough	B-22
Mac	1982	Midlatitude Trough	B-23
Alex	1984	Terrain Interaction	B-24
Ike	1984	Terrain Interaction	B-25
Gerald	1984	SW Monsoon	B-26
Ruth	1983	NE Monsoon	B-27
Sperry	1983	NE Monsoon	B-28
Thelma	1983	NE Monsoon	B-29
Ellis	1982	TUTT	B-30



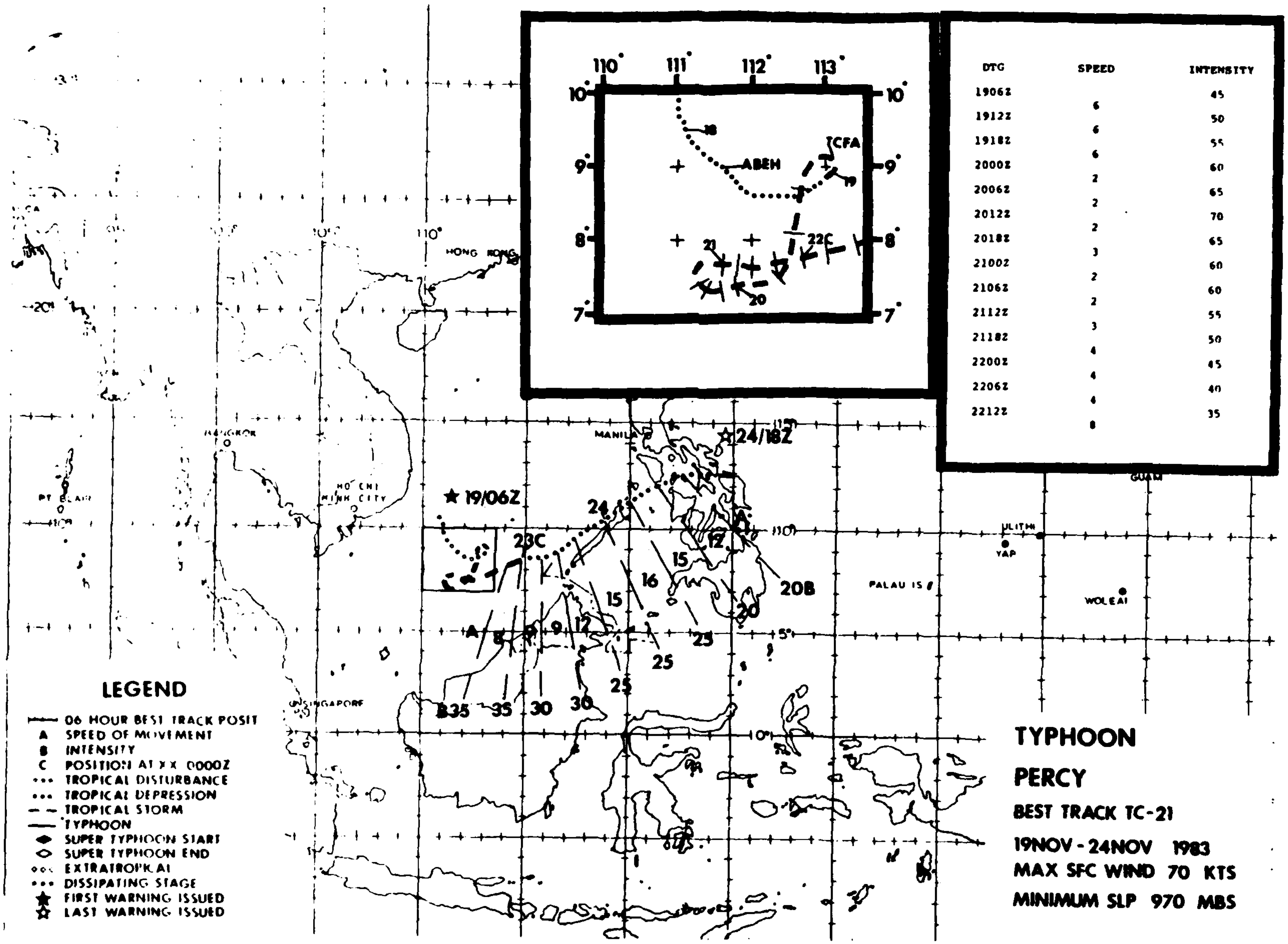
TYPHOON ORCHID

BEST TRACK TC-20

17NOV - 27 NOV 1983
MAX SFC WIND 125 KTS
MINIMUM SLP 928 MBS

DTG	SPEED	INTENSITY
1812Z	9	45
1818Z	4	50
1900Z	4	50
1906Z	4	55
1912Z	3	60
1918Z	2	65
2000Z	2	70
2006Z	6	75
2012Z	6	80
2018Z	4	85
2100Z	4	90
2106Z	5	95
2112Z	4	100
2118Z	5	100
2200Z	4	100
2206Z	4	105
2212Z	4	105
2218Z	4	110

DTG	SPEED	INTENSITY
2300Z	4	110
2306Z	4	120
2312Z	2	125
2318Z	2	120
2400Z	3	110
2406Z	2	100
2412Z	3	95
2418Z	4	85
2500Z	3	75
2506Z	2	65
2512Z	5	55
2518Z	5	50
2600Z	6	50
2606Z	6	45
2612Z	10	40
2618Z	11	35
2700Z	15	30



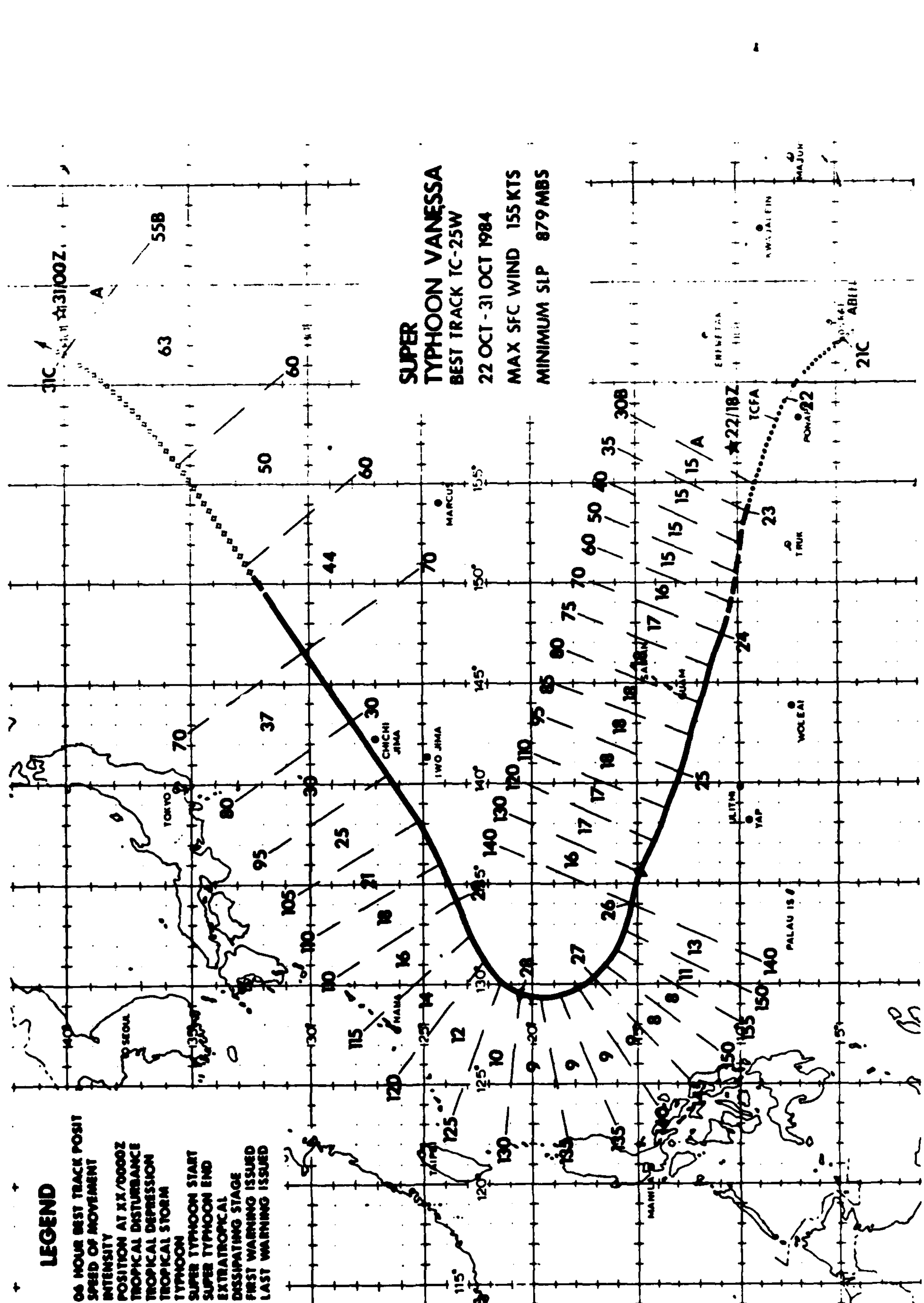
DTG	SPEED	INTENSITY
1906Z	6	45
1912Z	6	50
1918Z	6	55
2000Z	2	60
2006Z	2	65
2012Z	2	70
2018Z	3	65
2100Z	2	60
2106Z	2	60
2112Z	3	55
2118Z	4	50
2200Z	4	45
2206Z	4	40
2212Z	8	35

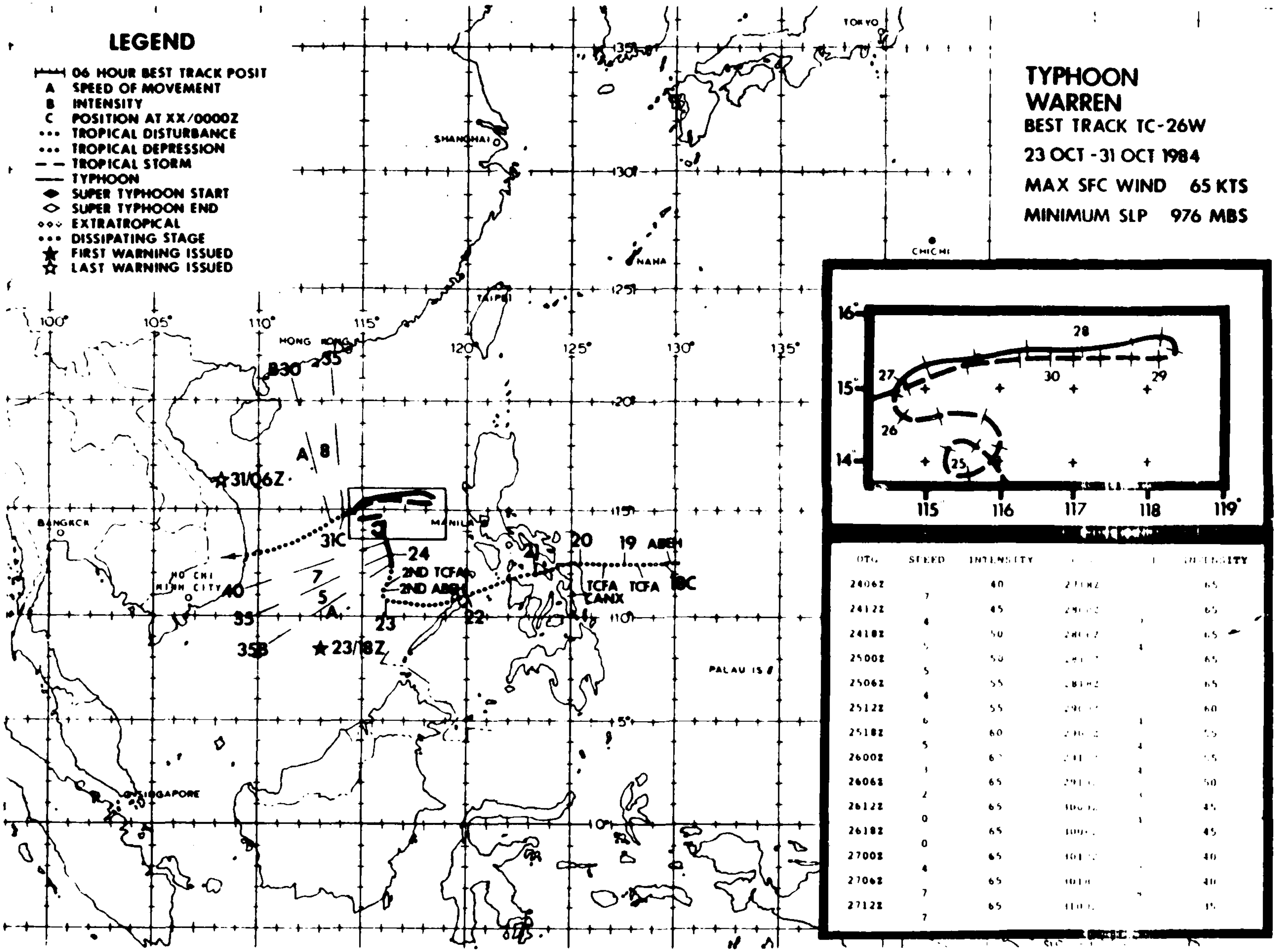
TYPHOON

PERCY

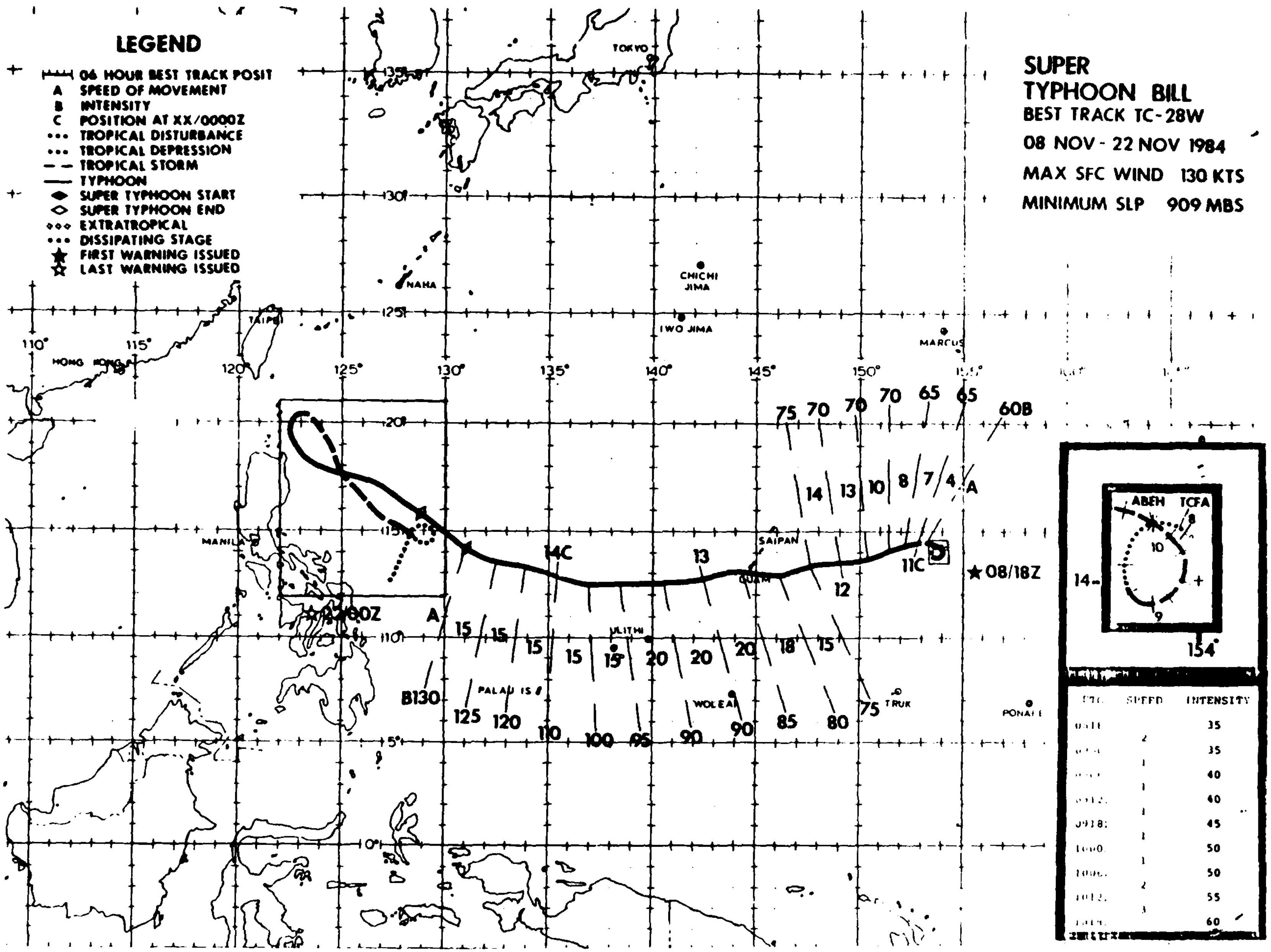
BEST TRACK TC-21

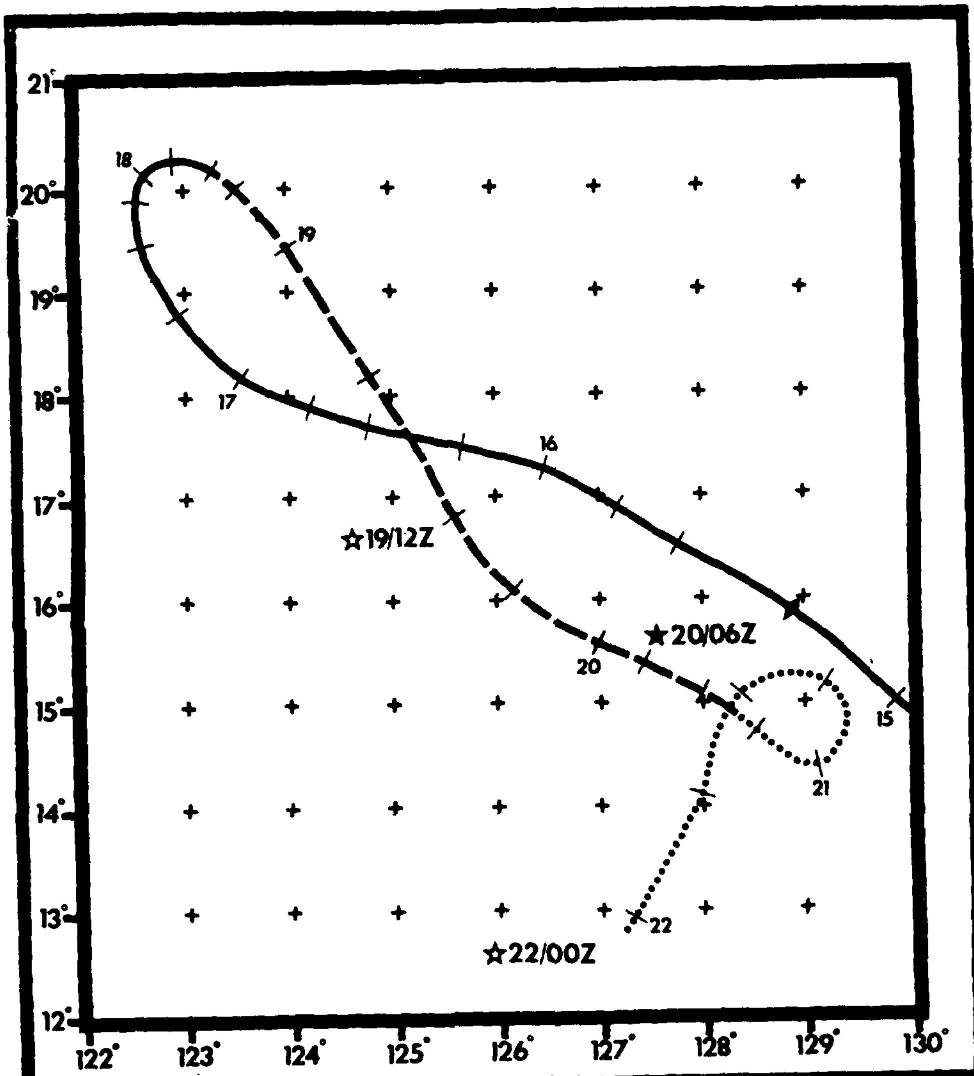
19NOV-24NOV 1983
MAX SFC WIND 70 KTS
MINIMUM SLP 970 MBS


LEGEND
06 HOUR BEST TRACK POSIT
SPEED OF MOVEMENT
INTENSITY
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SUPER
TYPHOON VANESSA
BEST TRACK TC-25W
22 OCT - 31 OCT 1984
MAX SFC WIND 155 KTS
MINIMUM SLP 879 MBS
31/00Z
22/18Z
TCFA
TOKYO
IWO JIMA
CHICHI JIMA
MARCUS
GUAM
SAIPAN
YAP
WOLEAI
TRUK
PONAPE
PALAU IS
MANILA
NAHA
SEOUL
TAIPEI

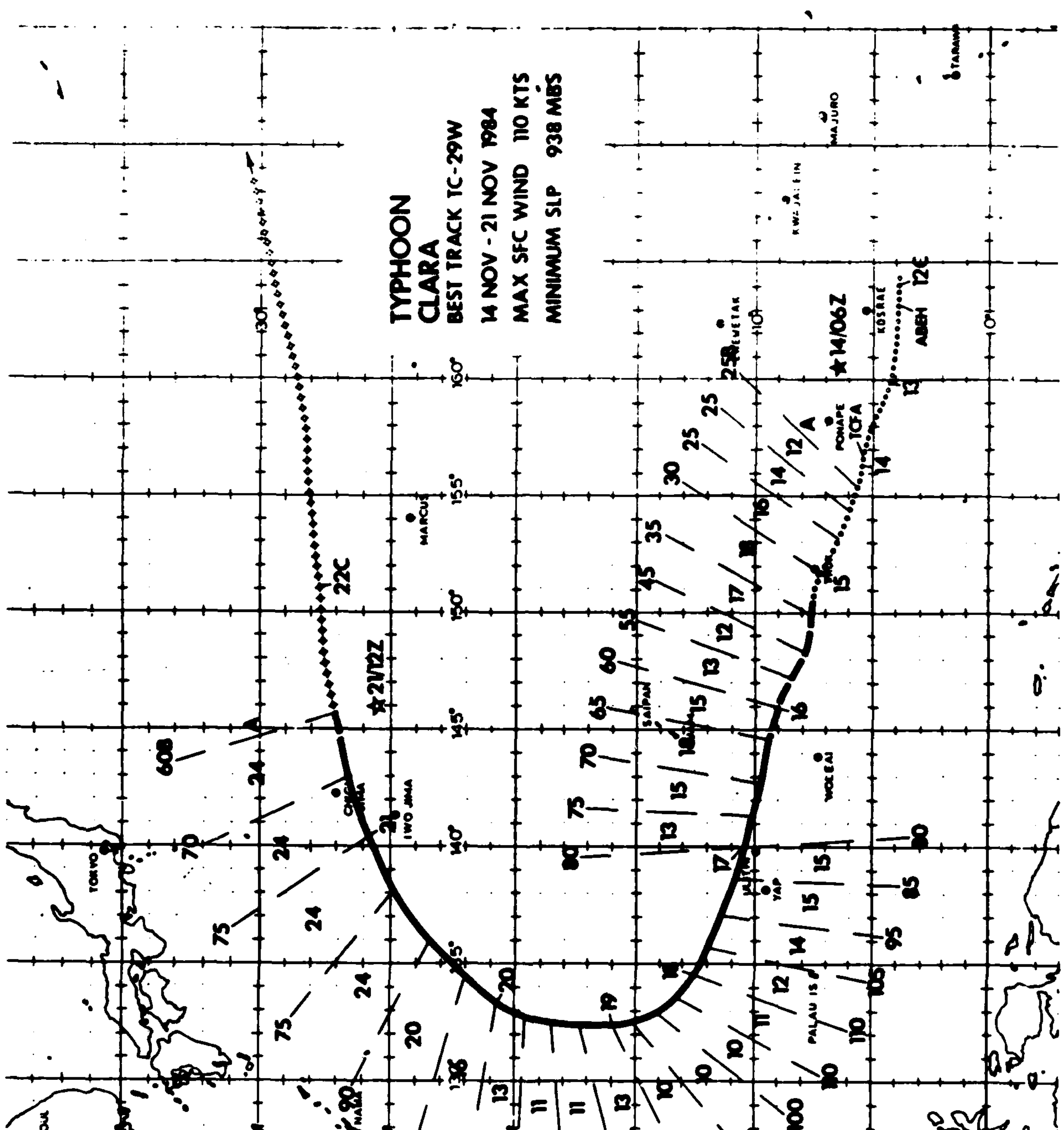


DTG	SPEED	INTENSITY	[illegible]	[illegible]	INTENSITY
24062	7	40	[illegible]	[illegible]	65
24122	4	45	[illegible]	[illegible]	65
24182	5	50	[illegible]	[illegible]	65
25002	5	50	[illegible]	[illegible]	65
25062	4	55	[illegible]	[illegible]	65
25122	6	55	[illegible]	[illegible]	60
25182	5	60	[illegible]	[illegible]	55
26002	1	6[illegible]	[illegible]	[illegible]	55
26062	2	65	[illegible]	[illegible]	50
26122	0	65	[illegible]	[illegible]	45
26182	0	65	[illegible]	[illegible]	45
27002	4	65	[illegible]	[illegible]	40
27062	7	65	[illegible]	[illegible]	40
27122	7	65	[illegible]	[illegible]	35

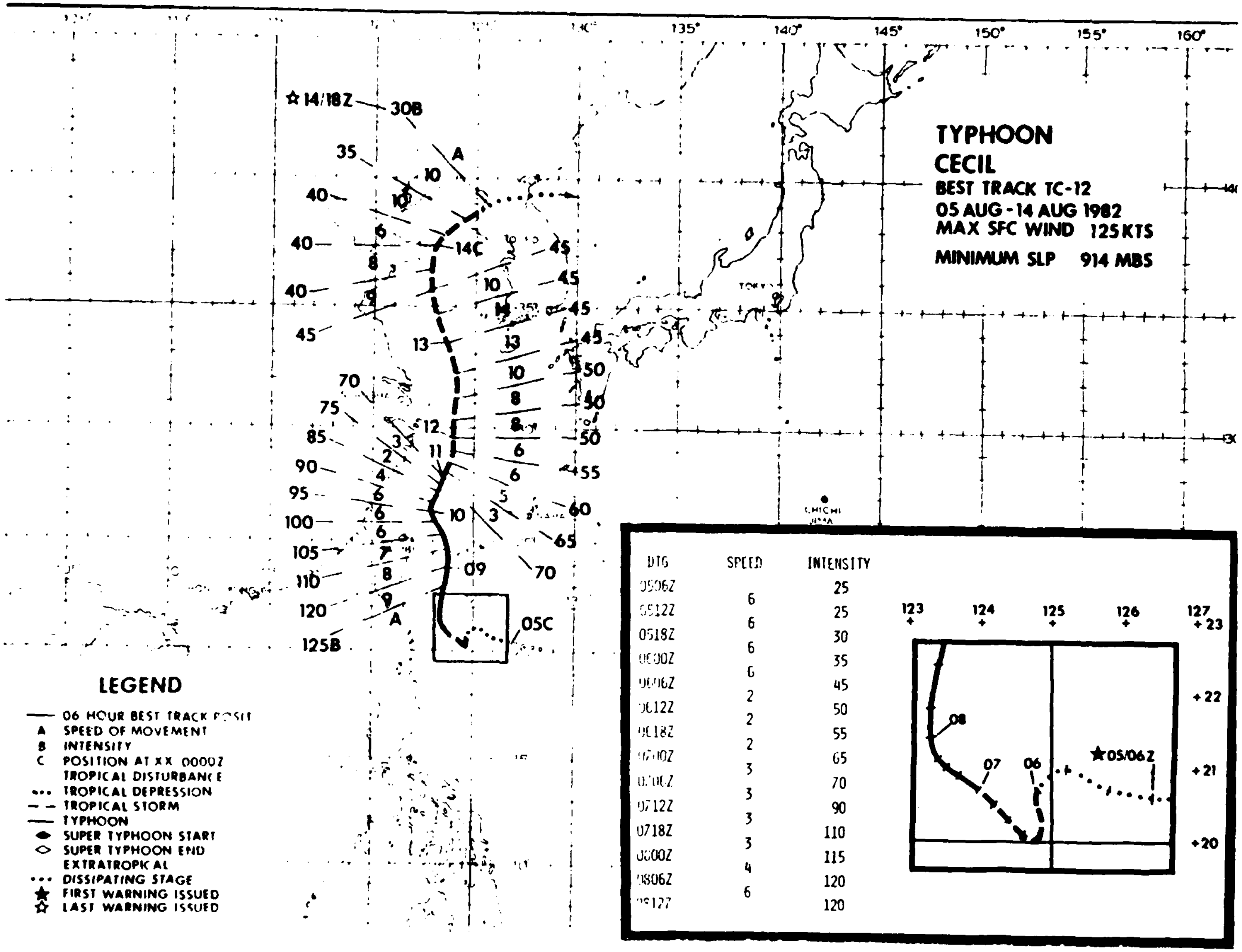

SUPER
TYPHOON BILL
BEST TRACK TC-28W
08 NOV - 22 NOV 1984
MAX SFC WIND 130 KTS
MINIMUM SLP 909 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
NAHA
TAIPEI
HONG KONG
MANILA
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
ULITHI
PALAU IS
WOLEAI
TRUK
PONAPE
★ 08/18Z
11C
14C
ABEH
TCFA
SPEED
INTENSITY



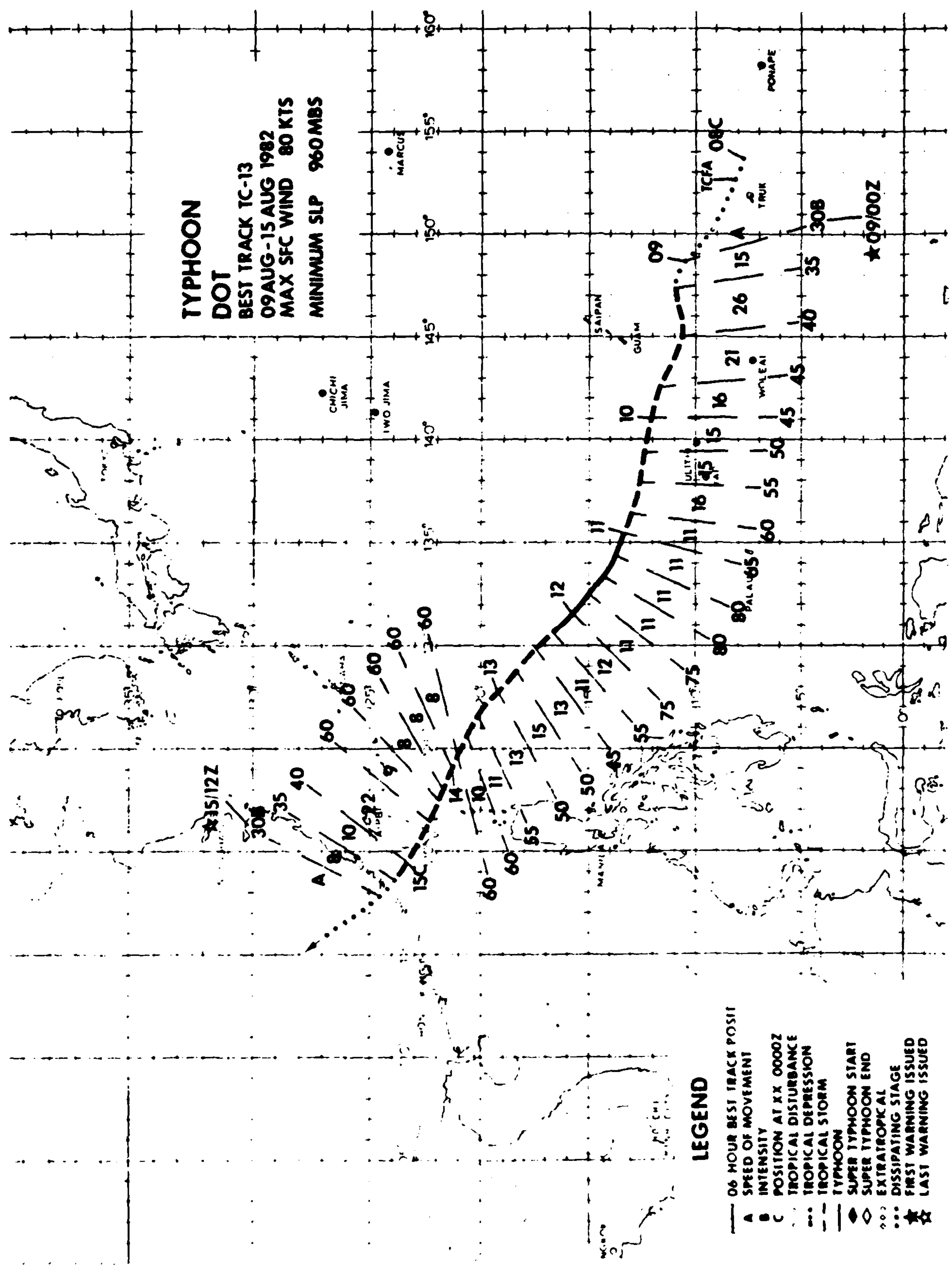
DTG	SPEED	INTENSITY	DTG	SPEED	INTENSITY
1418Z	14	130	1812Z	3	65
1500Z	13	130	1818Z	7	60
1506Z	12	130	1900Z	14	55
1512Z	7	125	1906Z	16	50
1518Z	6	125	1912Z	9	50
1600Z	8	120	1918Z	8	45
1606Z	8	120	2000Z	5	45
1612Z	7	115	2006Z	5	40
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	40
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30
1712Z	5	90	2106Z	7	30
1718Z	4	80	2112Z	11	25
1800Z	3	80	2118Z	13	25
1806Z	3	70	2200Z		25

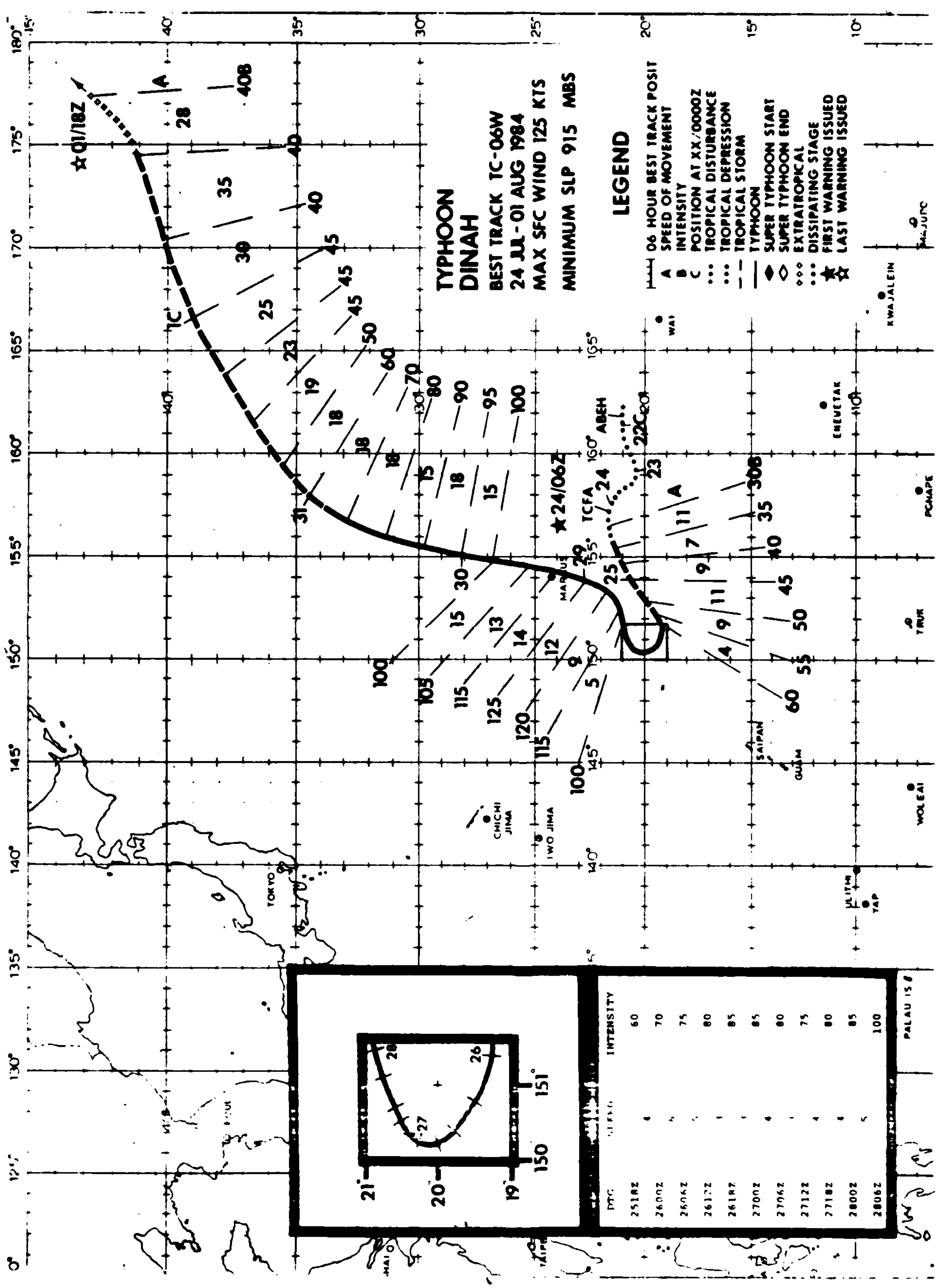


LEGEND
06 HOUR BEST TRACK POSIT
SPEED OF MOVEMENT
INTENSITY
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TYPHOON
CLARA
BEST TRACK TC-29W
14 NOV - 21 NOV 1984
MAX SFC WIND 110 KTS
MINIMUM SLP 938 MBS
21/12Z
14/06Z
TCFA
TOKYO
IWO JIMA
MARCUS
SAIPAN
GUAM
YAP
WOLEAI
PALAU IS
PONAPE
KOSRAE
ENIWETAK
KWAJALEIN
MAJURO
TARAWA
MANILA
TAIPEI
NAHA

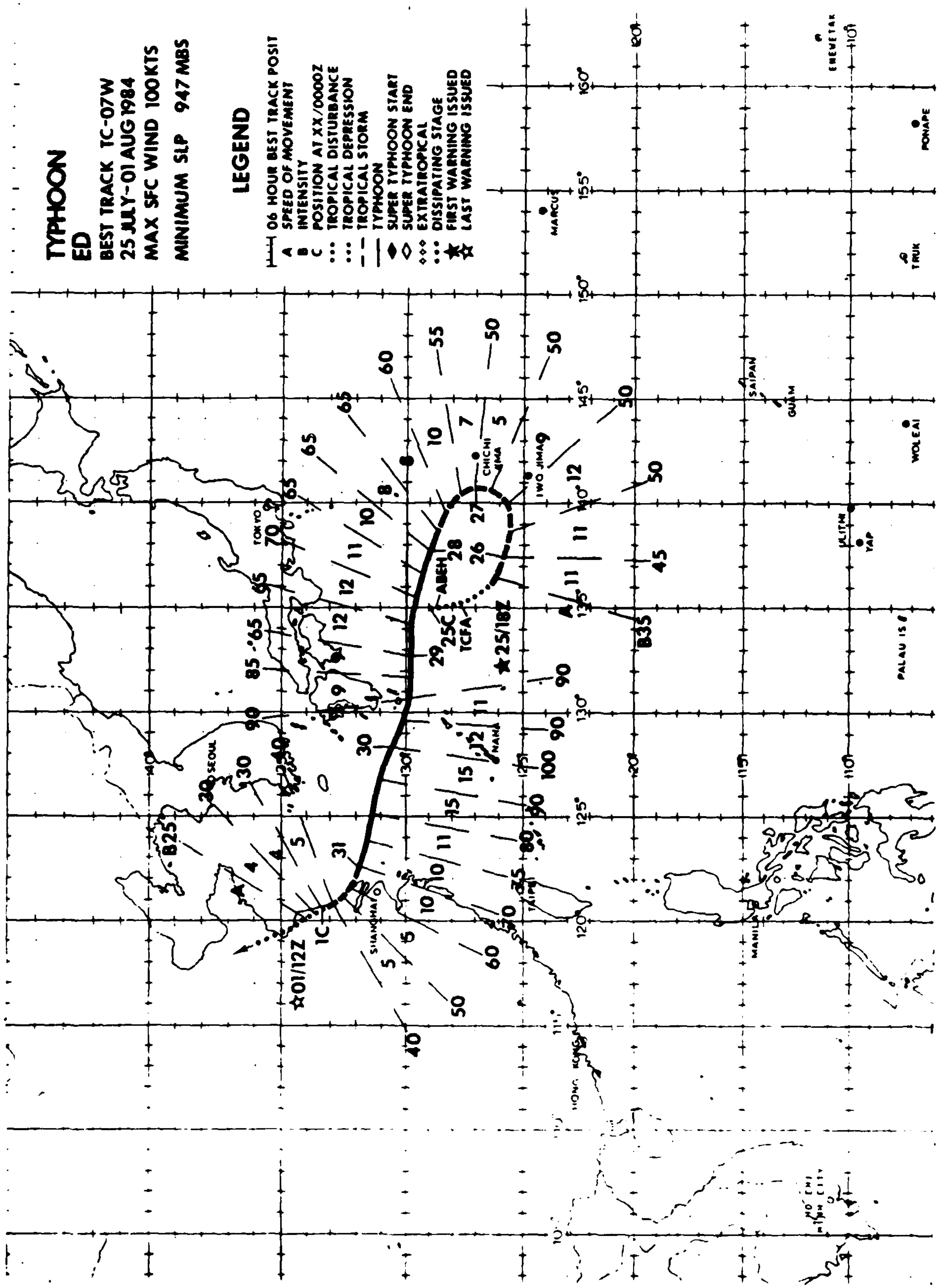


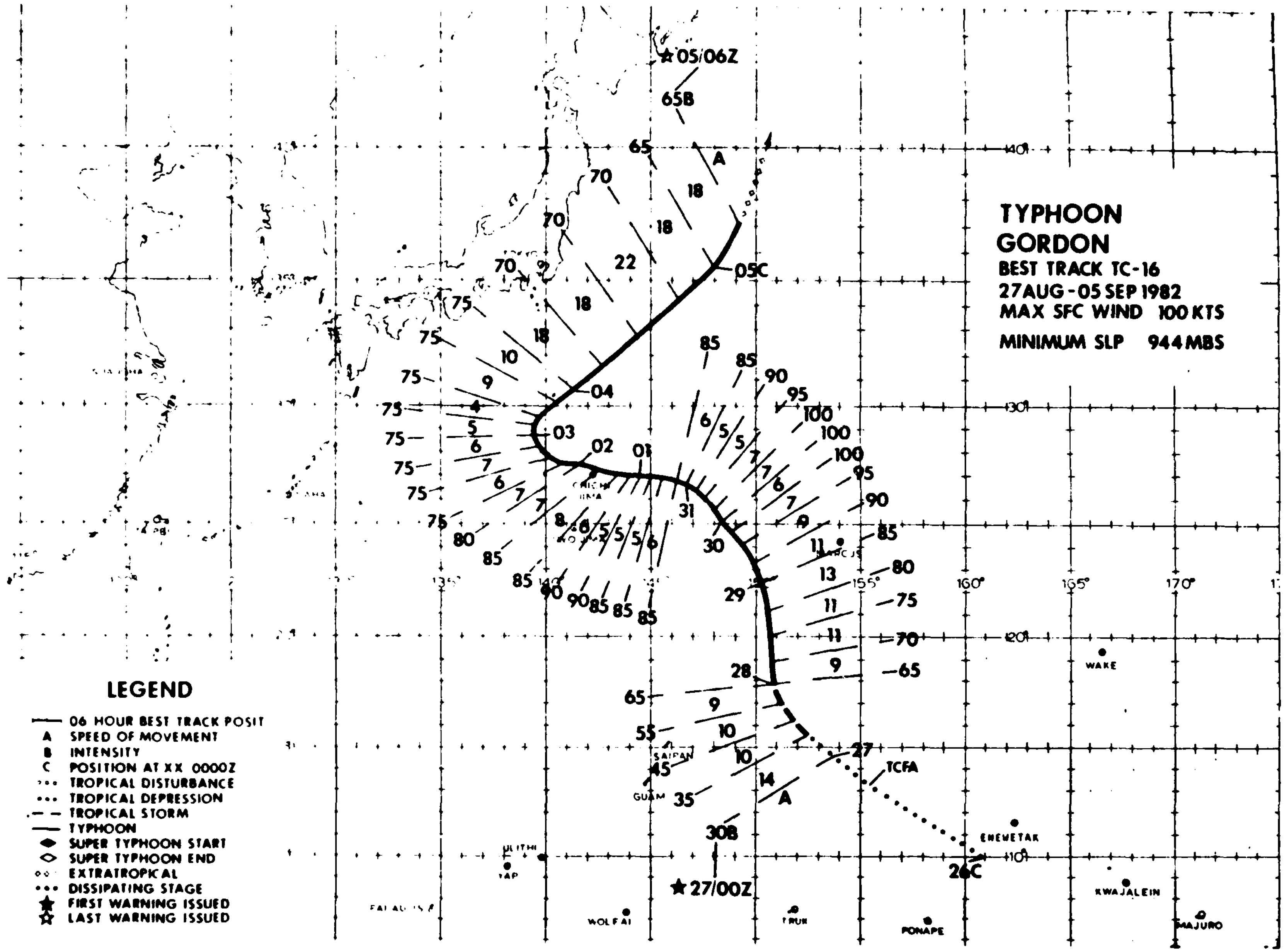
DTG	SPEED	INTENSITY
0506Z	6	25
0512Z	6	25
0518Z	6	30
0600Z	6	35
0606Z	2	45
0612Z	2	50
0618Z	2	55
0700Z	3	65
0706Z	3	70
0712Z	3	90
0718Z	3	110
0800Z	4	115
0806Z	6	120
0812Z		120


TYPHOON
DOT
BEST TRACK TC-13
09AUG-15AUG 1982
MAX SFC WIND 80 KTS
MINIMUM SLP 960 MBS
LEGEND
06 HOUR BEST TRACK POSIT
SPEED OF MOVEMENT
INTENSITY
POSITION AT XX 0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
MARCUS
PONAPE
TRUK
SAIPAN
GUAM
WOLEAI
CHICHI JIMA
IWO JIMA
ULITHI
PALAU
MANILA
TCFA
08C
09/00Z
15/12Z
160°
155°
150°
145°
140°
135°

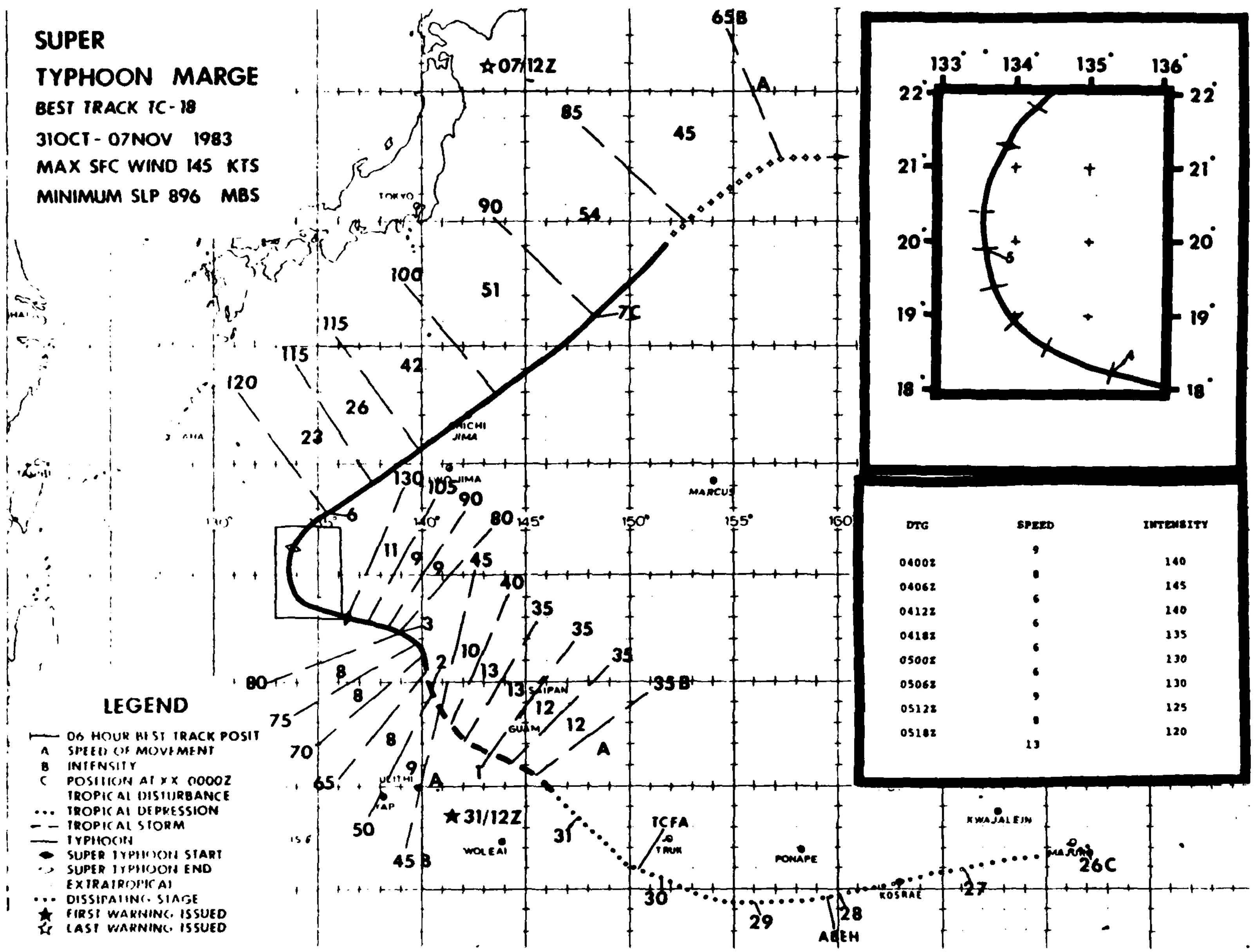


TYPHOON
DINAH
BEST TRACK TC-06W
24 JUL - 01 AUG 1984
MAX SFC WIND 125 KTS
MINIMUM SLP 915 MBS
LEGEND
06 HOUR BEST TRACK POSIT
SPEED OF MOVEMENT
INTENSITY
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
01/18Z
24/06Z
TCFA
TOKYO
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
WOLEAI
YAP
TRUK
PONAPE
ENEWETAK
KWAJALEIN
INTENSITY


TYPHOON
ED
BEST TRACK TC-07W
25 JULY-01 AUG 1984
MAX SFC WIND 100KTS
MINIMUM SLP 947 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
SEOUL
SHANGHAI
TAIPEI
MANILA
HONG KONG
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
WOLEAI
TRUK
PONAPE
ENEWETAK
YAP
ULITHI
PALAU IS
★25/18Z
☆01/12Z
ABEH
TCFA
B25
B35



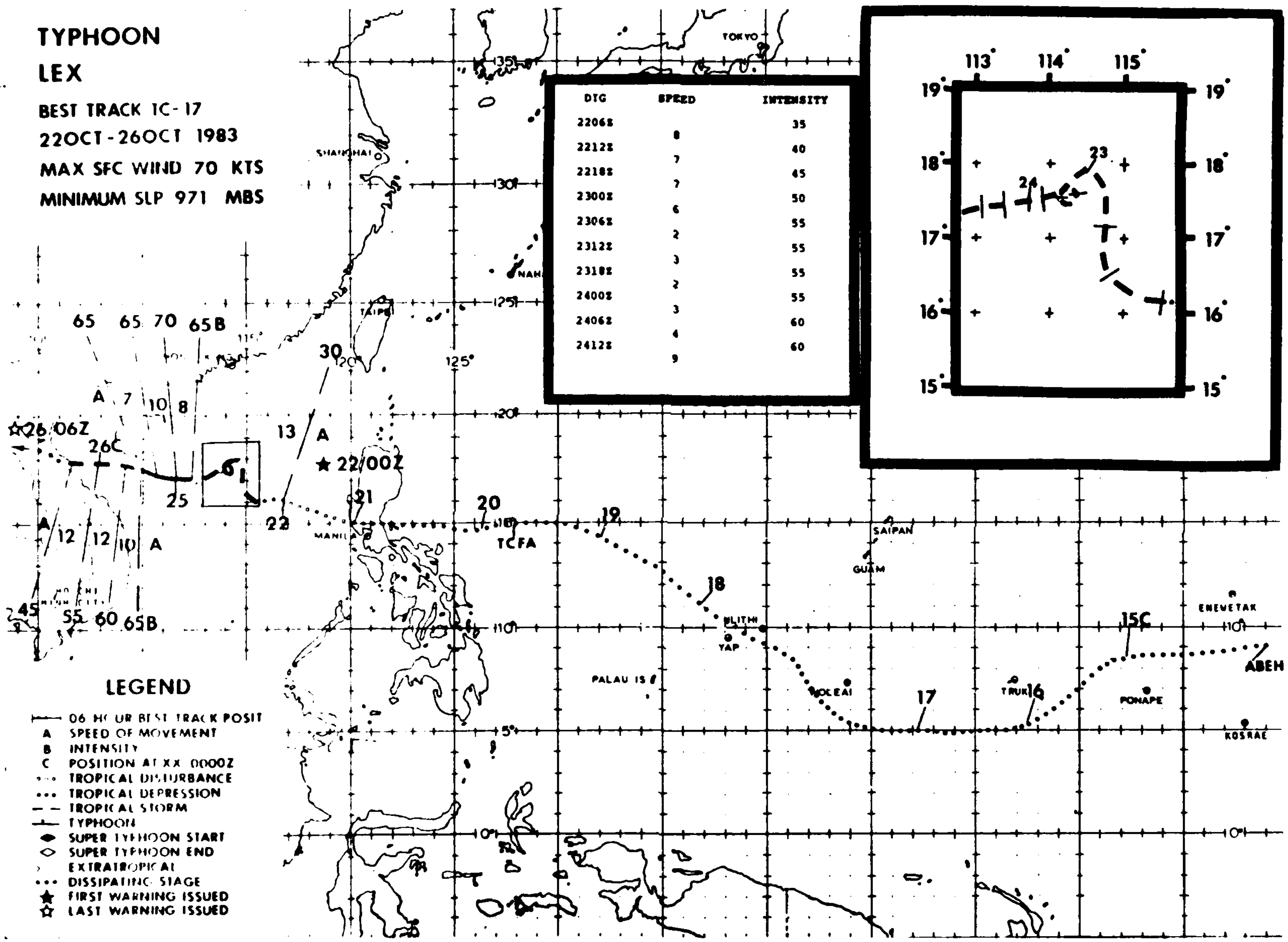
TYPHOON
GORDON
BEST TRACK TC-16
27AUG-05 SEP 1982
MAX SFC WIND 100 KTS
MINIMUM SLP 944 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX 0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
05/06Z
65B
05C
27/00Z
30B
26C
TCFA
WAKE
ENEWETAK
KWAJALEIN
MAJURO
PONAPE
TRUK
WOLEAI
ULITHI
YAP
GUAM
SAIPAN
MARCUS



DTG	SPEED	INTENSITY
	9	
0400Z	8	140
0406Z	6	145
0412Z	6	140
0418Z	6	135
0500Z	6	130
0506Z	9	130
0512Z	8	125
0518Z	13	120

TYPHOON
LEX

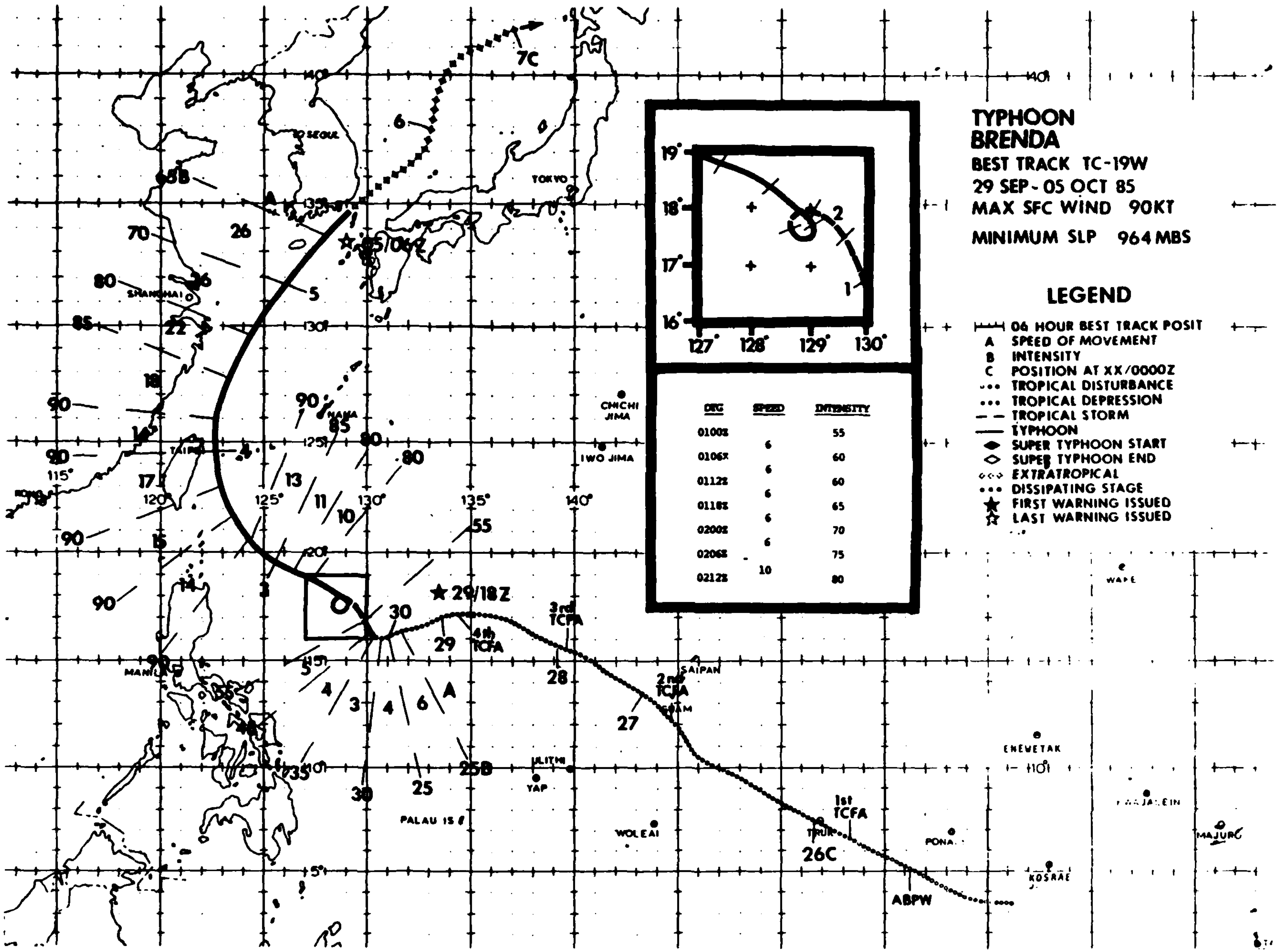
BEST TRACK IC-17
22OCT-26OCT 1983
MAX SFC WIND 70 KTS
MINIMUM SLP 971 MBS

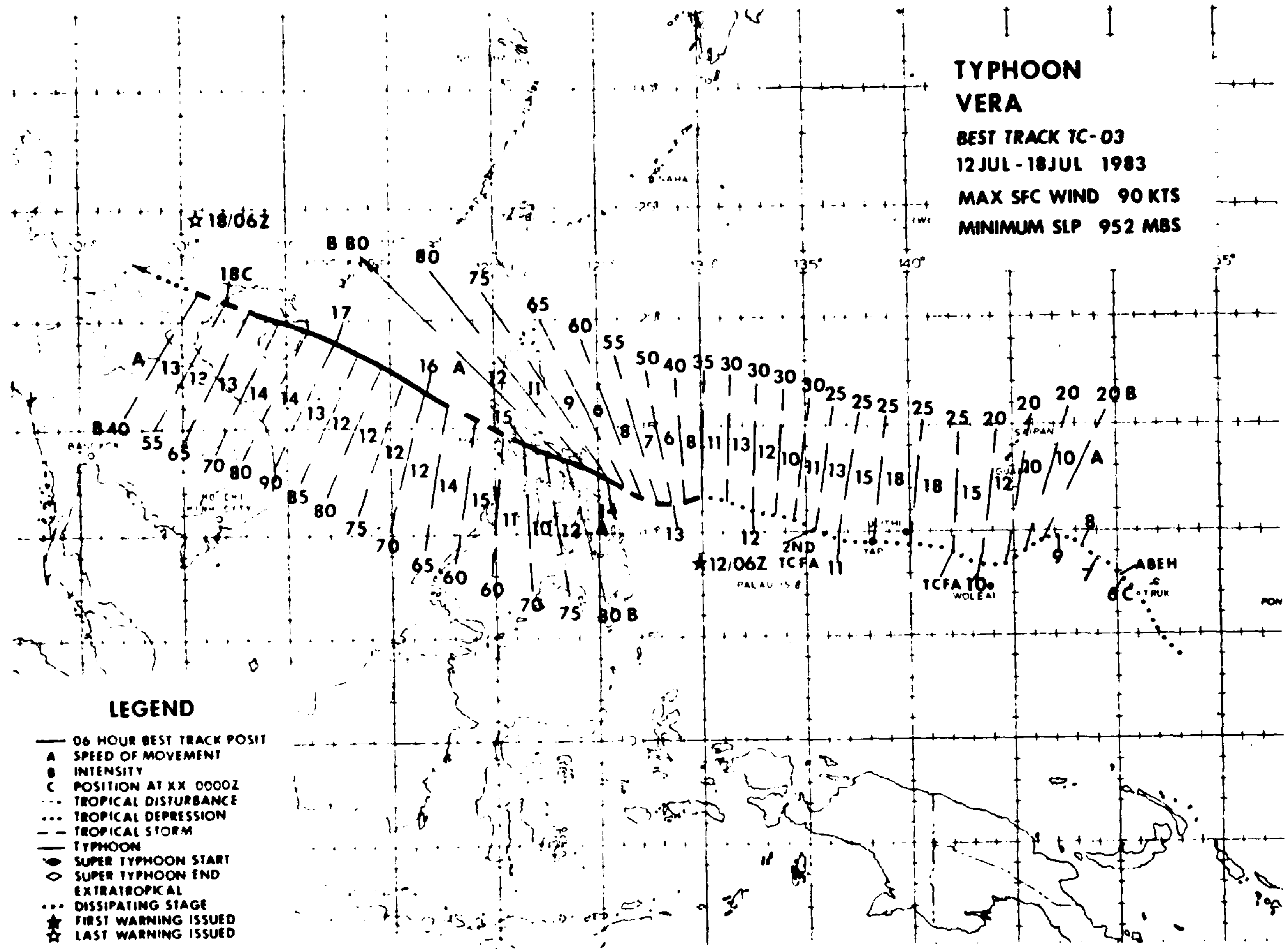


DTG	SPEED	INTENSITY
2206Z	8	35
2212Z	7	40
2218Z	7	45
2300Z	6	50
2306Z	2	55
2312Z	3	55
2318Z	2	55
2400Z	3	55
2406Z	4	60
2412Z	9	60

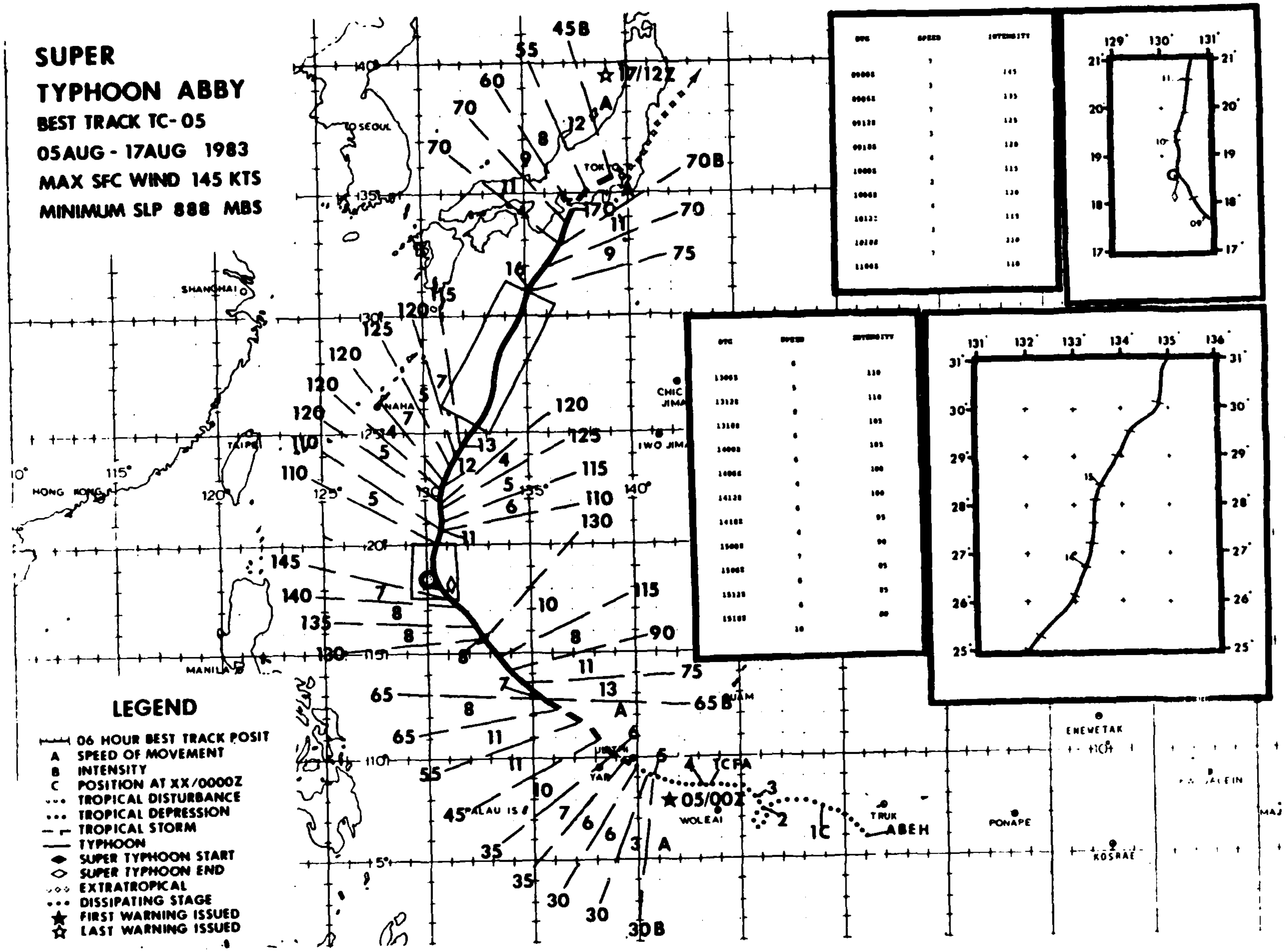
LEGEND

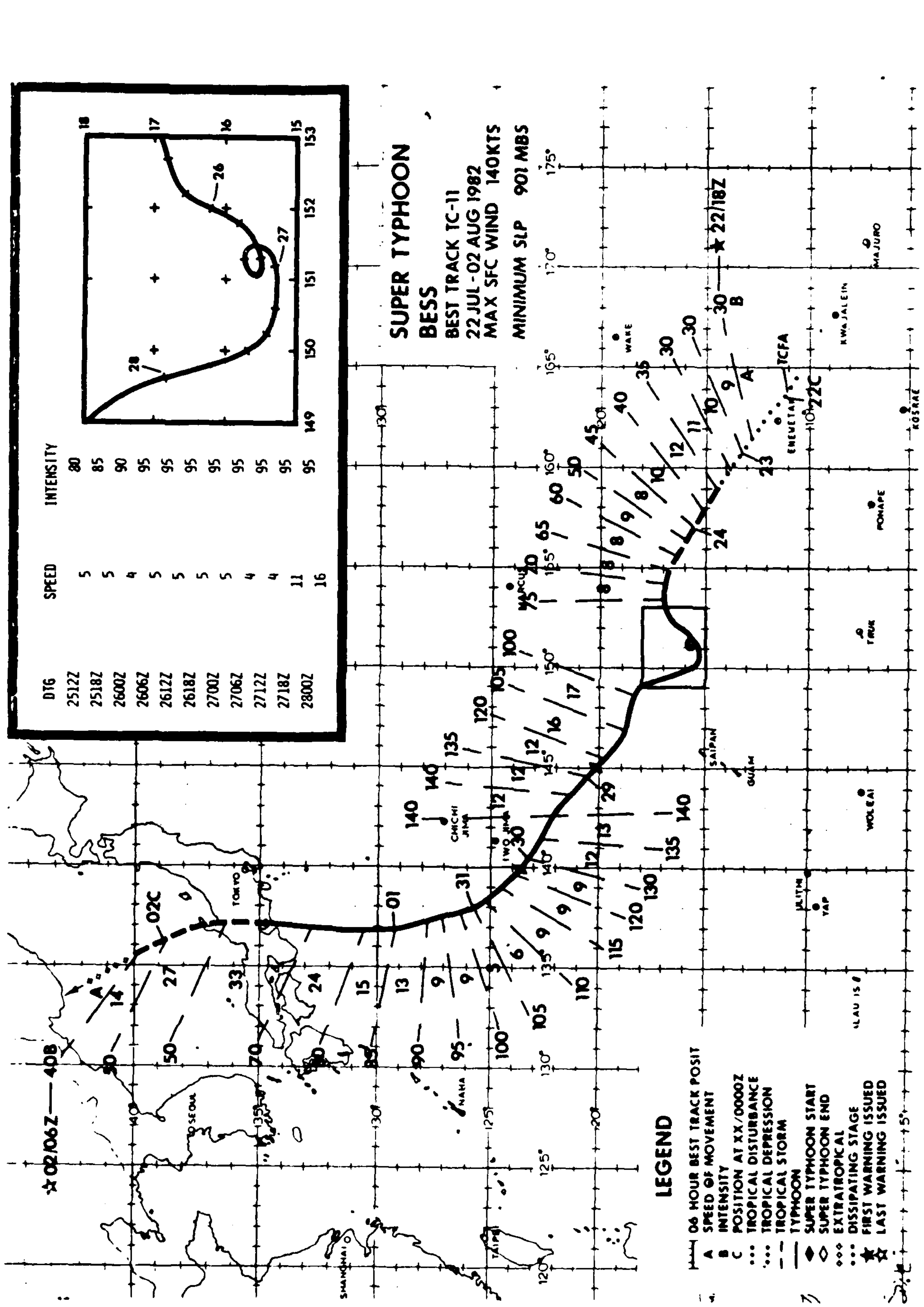
- 06 HOUR BEST TRACK POSIT
- A SPEED OF MOVEMENT
- B INTENSITY
- C POSITION AT XX 0000Z
- TROPICAL DISTURBANCE
- TROPICAL DEPRESSION
- TROPICAL STORM
- TYPHOON
- SUPER TYPHOON START
- SUPER TYPHOON END
- EXTRATROPICAL
- DISSIPATING STAGE
- ★ FIRST WARNING ISSUED
- ☆ LAST WARNING ISSUED

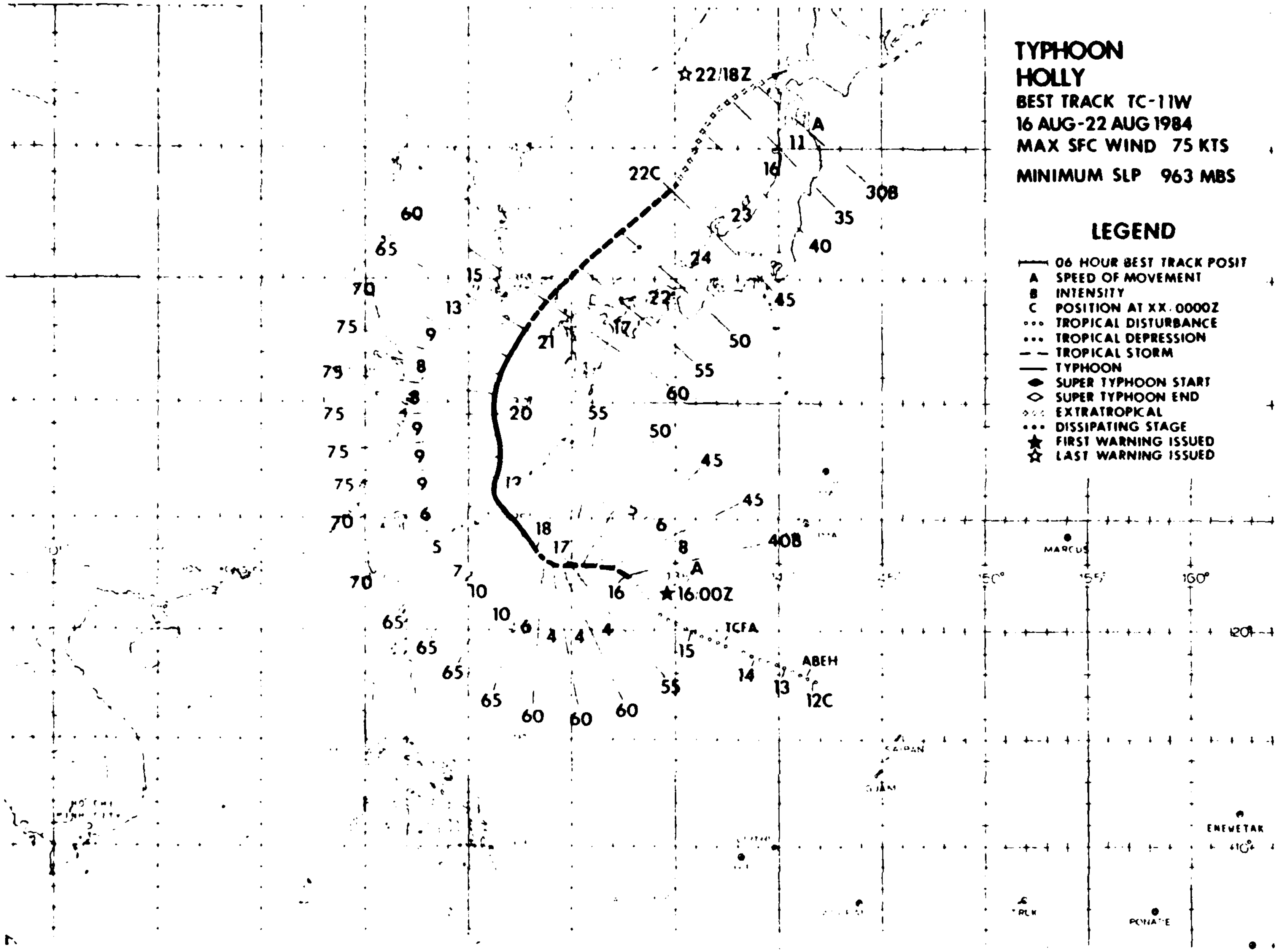

TYPHOON
BRENDA
BEST TRACK TC-19W
29 SEP - 05 OCT 85
MAX SFC WIND 90KT
MINIMUM SLP 964 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
DTG
SPEED
INTENSITY
0100Z 55
0106Z 60
0112Z 60
0118Z 65
0200Z 70
0206Z 75
0212Z 80
6
6
6
6
6
10
SEOUL
TOKYO
SHANGHAI
TAIPEI
MANILA
NAHA
CHICHI JIMA
IWO JIMA
SAIPAN
GUAM
ULITHI
YAP
PALAU IS
WOLEAI
TRUK
PONA
KOSRAE
ENEWETAK
WAKE
MAJURO
★ 29/18Z
1st TCFA
2nd TCFA
3rd TCFA
4th TCFA
ABPW
7C
26C
25B
05/06Z

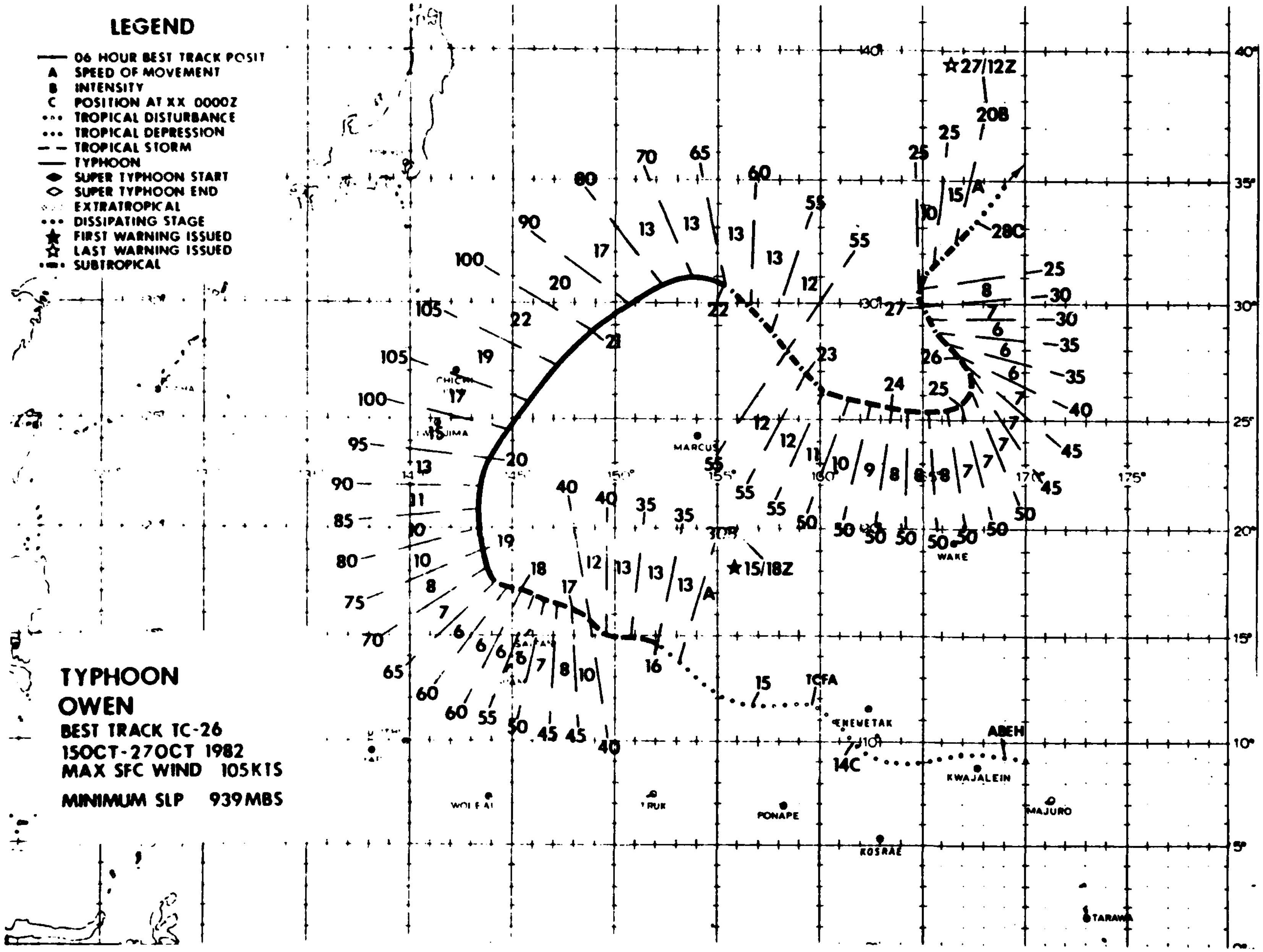


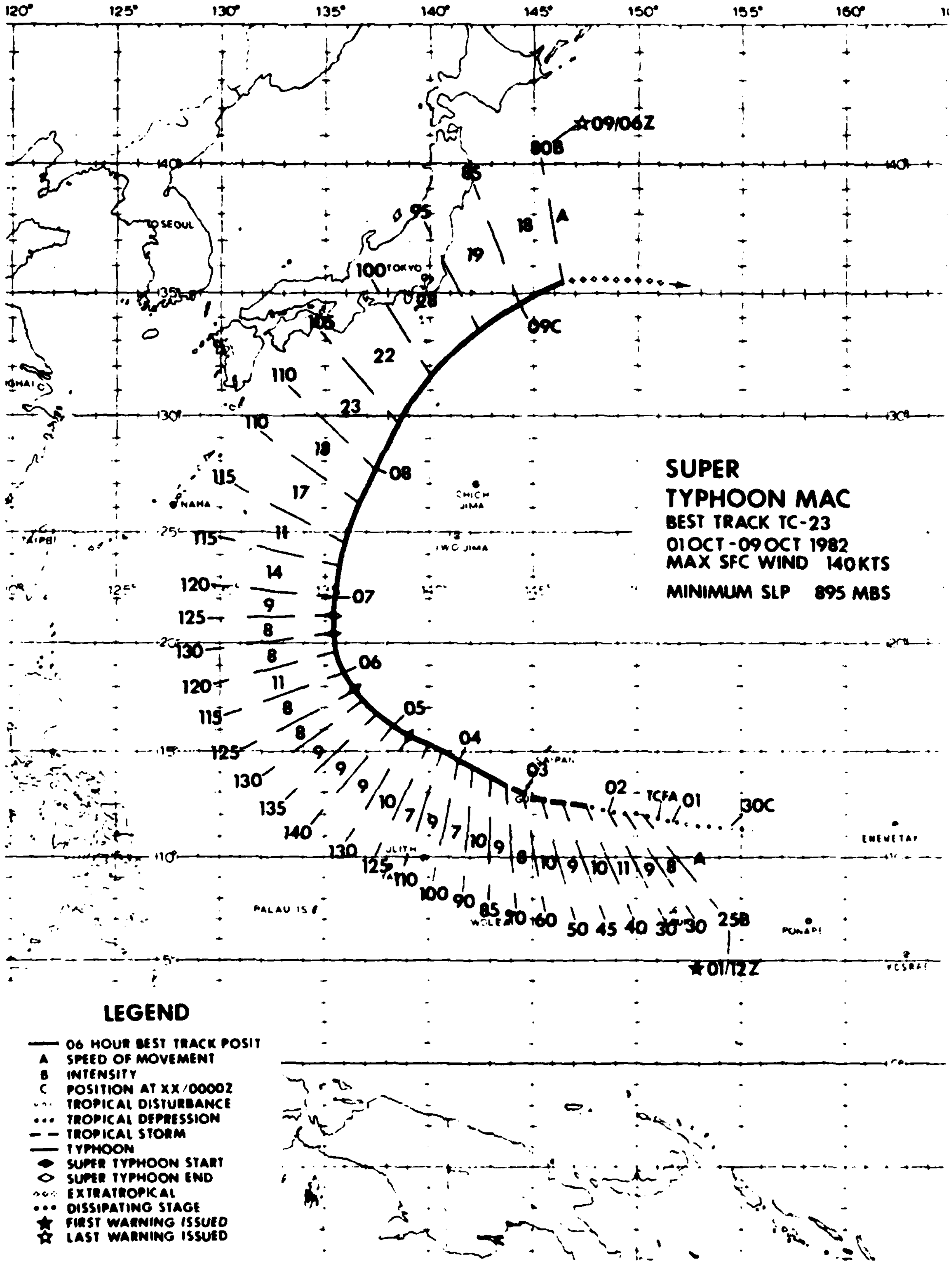
TYPHOON
VERA
BEST TRACK TC-03
12 JUL - 18 JUL 1983
MAX SFC WIND 90 KTS
MINIMUM SLP 952 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX 0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
18/06Z
18C
12/06Z
2ND TCFA
TCFA
ABEH
SAIPAN
WOLEAI
YAP
TRUK
135°
140°

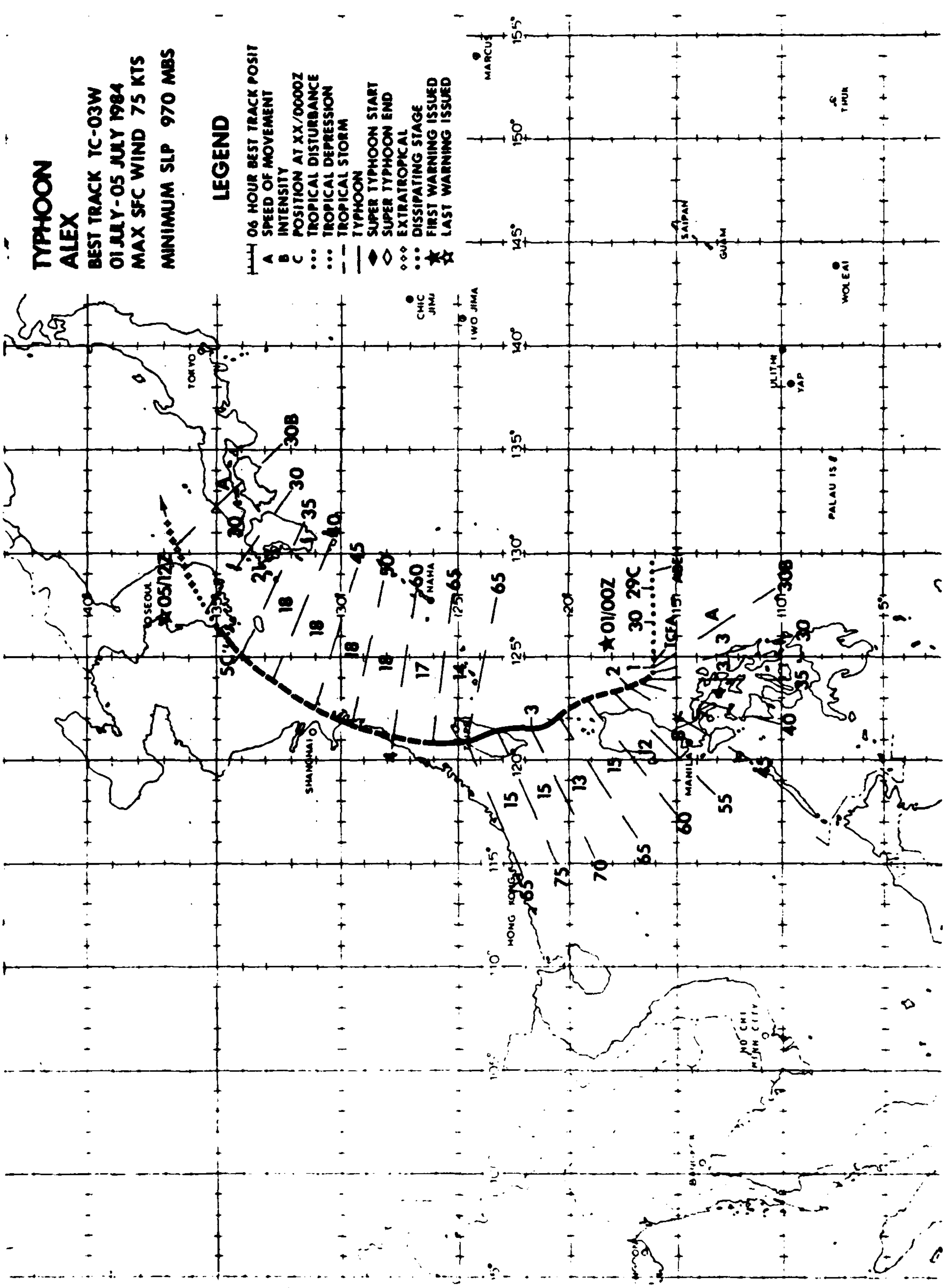

SUPER
TYPHOON ABBY
BEST TRACK TC-05
05AUG - 17AUG 1983
MAX SFC WIND 145 KTS
MINIMUM SLP 888 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
17/12Z
05/00Z
TCFA
ABEH
SEOUL
SHANGHAI
HONG KONG
TAIPEI
MANILA
NAHA
IWO JIMA
GUAM
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
ENEWETAK
KOSRAE

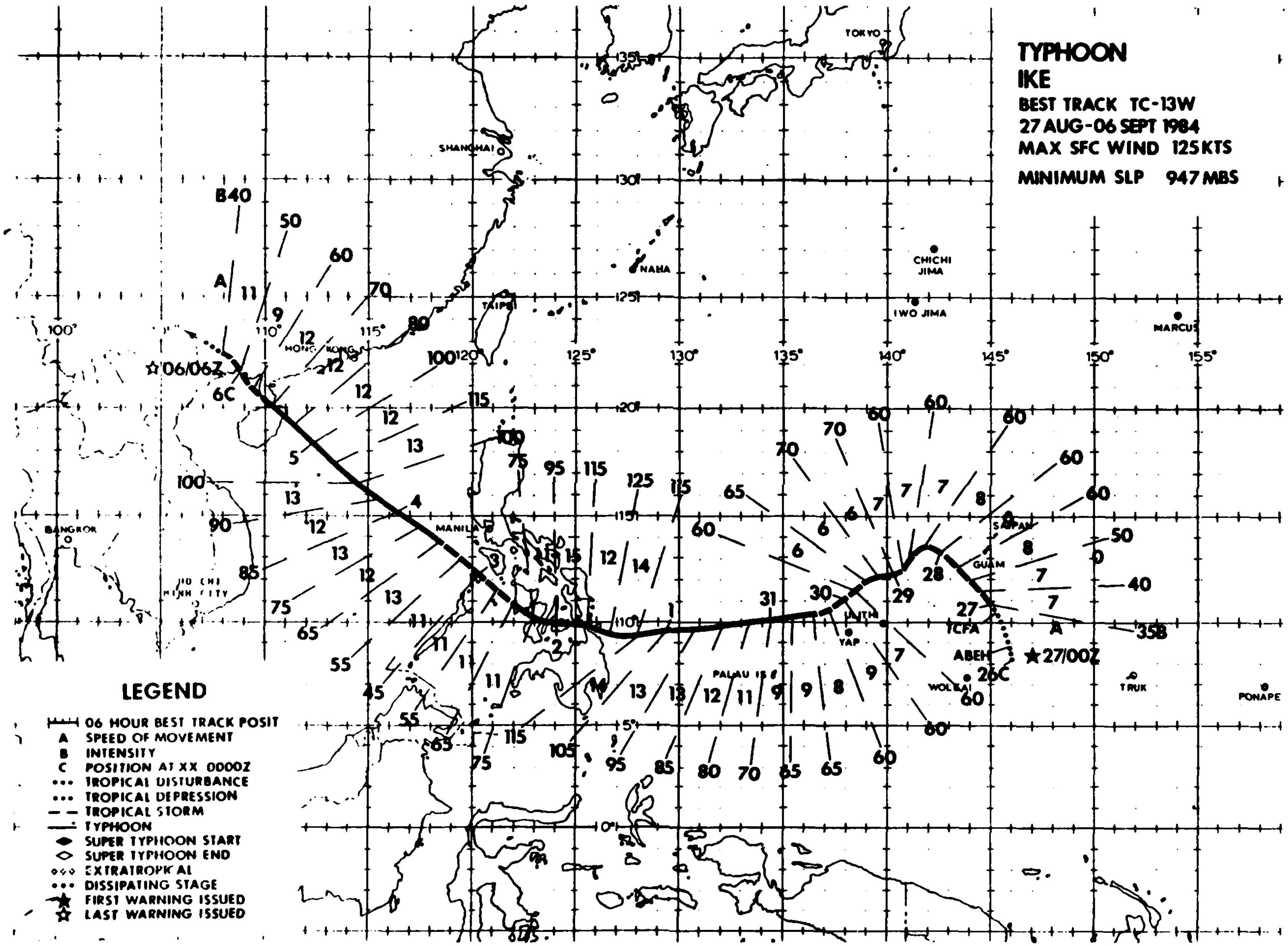

SUPER TYPHOON
BESS
BEST TRACK TC-11
22 JUL-02 AUG 1982
MAX SFC WIND 140KTS
MINIMUM SLP 901 MBS
DTG SPEED INTENSITY
2512Z 5 80
2518Z 5 85
2600Z 4 90
2606Z 5 95
2612Z 5 95
2618Z 5 95
2700Z 5 95
2706Z 4 95
2712Z 4 95
2718Z 11 95
2800Z 16 95
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
02/06Z
22/18Z
TCFA
SHANGHAI
SEOUL
TOKYO
TAIPEI
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
WOLEAI
YAP
TRUK
PONAPE
ENEWETAK
KOSRAE
KWAJALEIN
MAJURO

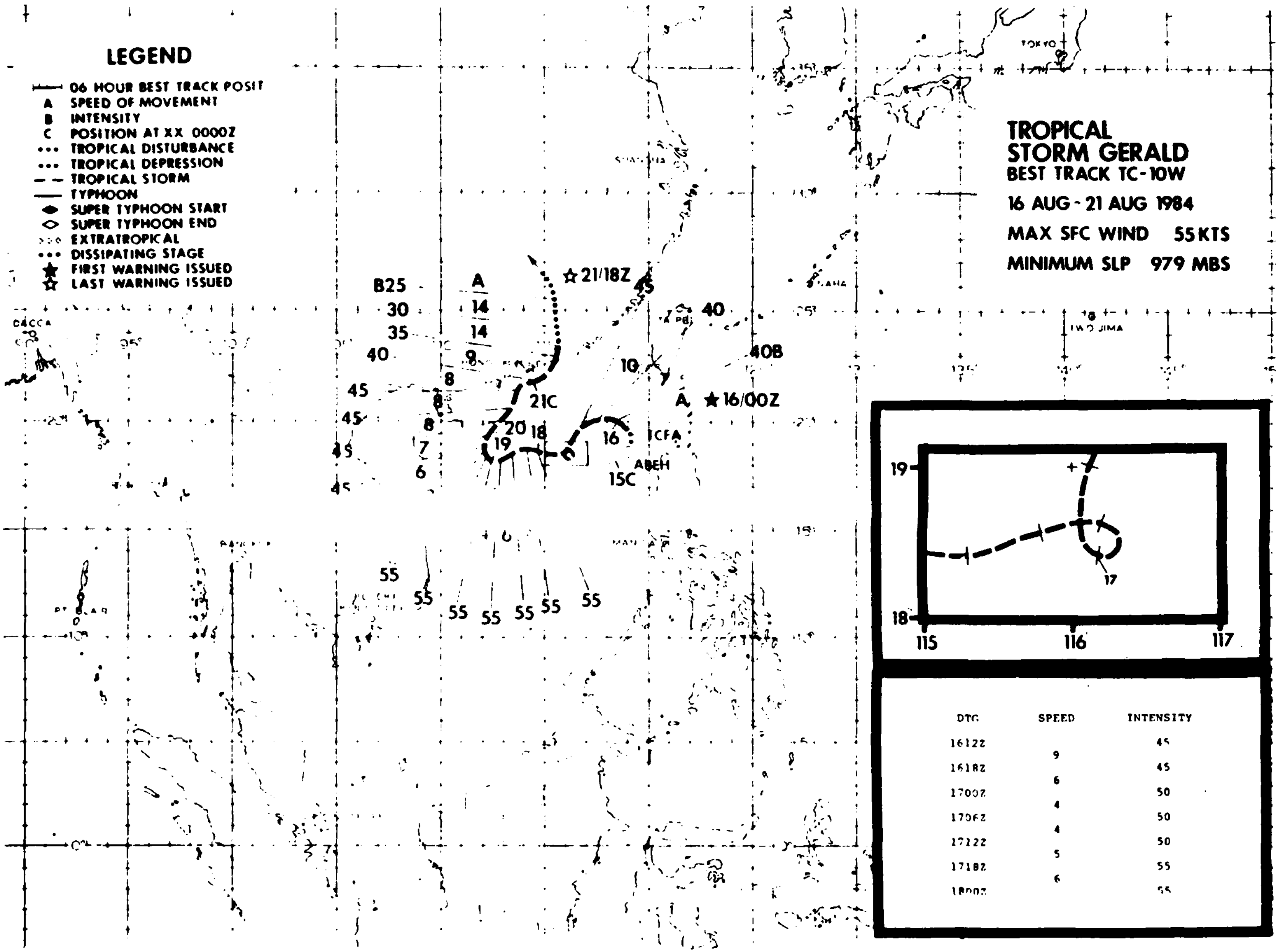

TYPHOON
HOLLY
BEST TRACK TC-11W
16 AUG-22 AUG 1984
MAX SFC WIND 75 KTS
MINIMUM SLP 963 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
☆22/18Z
★16/00Z
22C
12C
30B
40B
TCFA
ABEH
MARCUS
ENEWETAK
PONAPE
TRUK
SAIPAN
GUAM
150°
155°
160°
20°
10°


LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX 0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
SUBTROPICAL
TYPHOON
OWEN
BEST TRACK TC-26
15OCT-27OCT 1982
MAX SFC WIND 105KTS
MINIMUM SLP 939MBS
★15/18Z
☆27/12Z
TCFA
ABEH
MARCUS
WAKE
ENEWETAK
KWAJALEIN
MAJURO
PONAPE
KOSRAE
TRUK
WOLEAI
TARAWA
CHICHI
175°
40°
35°
30°
25°
20°
15°
10°
5°


SUPER
TYPHOON MAC
BEST TRACK TC-23
01 OCT - 09 OCT 1982
MAX SFC WIND 140 KTS
MINIMUM SLP 895 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
09/06Z
01/12Z
TCFA
SEOUL
TOKYO
NAHA
TAIPEI
IWO JIMA
CHICHI JIMA
PALAU IS
SAIPAN
PONAPE
ENEWETAK
KOSRAE


TYPHOON
ALEX
BEST TRACK TC-03W
01 JULY-05 JULY 1984
MAX SFC WIND 75 KTS
MINIMUM SLP 970 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TOKYO
SEOUL
SHANGHAI
NAHA
HONG KONG
MANILA
IWO JIMA
MARCUS
SAIPAN
GUAM
YAP
ULITHI
WOLEAI
PALAU IS
TRUK
HO CHI MINH CITY
05/12Z
01/00Z


TYPHOON
IKE
BEST TRACK TC-13W
27 AUG-06 SEPT 1984
MAX SFC WIND 125 KTS
MINIMUM SLP 947 MBS
TOKYO
SHANGHAI
NAHA
TAIPEI
CHICHI JIMA
IWO JIMA
MARCUS
HONG KONG
MANILA
BANGKOK
HO CHI MINH CITY
SAIPAN
GUAM
YAP
PALAU IS
WOLEAI
TRUK
PONAPE
☆06/06Z
★27/00Z
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX 0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED



DTG	SPEED	INTENSITY
1612Z		45
1618Z	9	45
1700Z	6	50
1706Z	4	50
1712Z	4	50
1718Z	5	55
1800Z	6	55

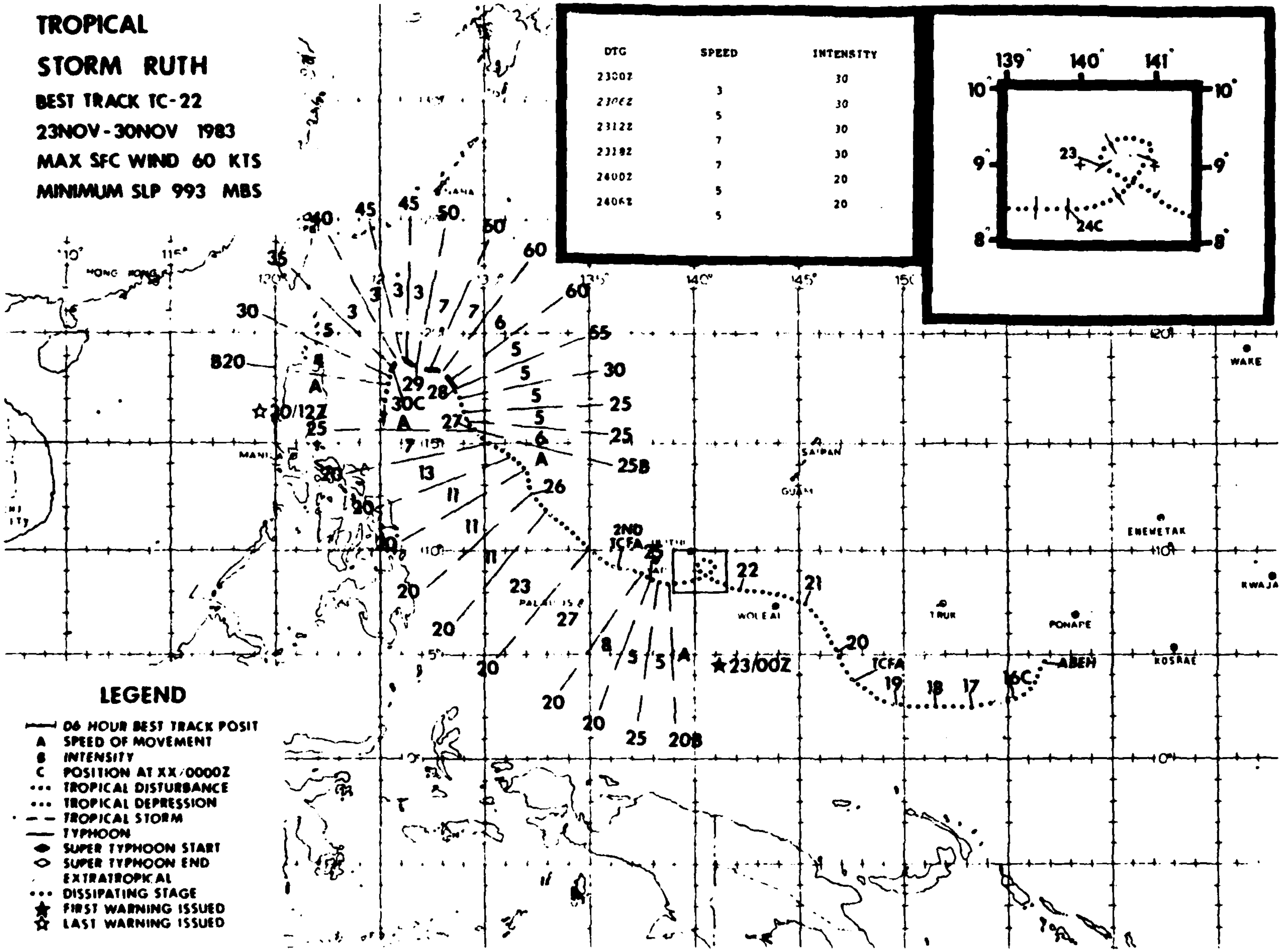
TROPICAL STORM RUTH

BEST TRACK TC-22

23NOV-30NOV 1983

MAX SFC WIND 60 KTS

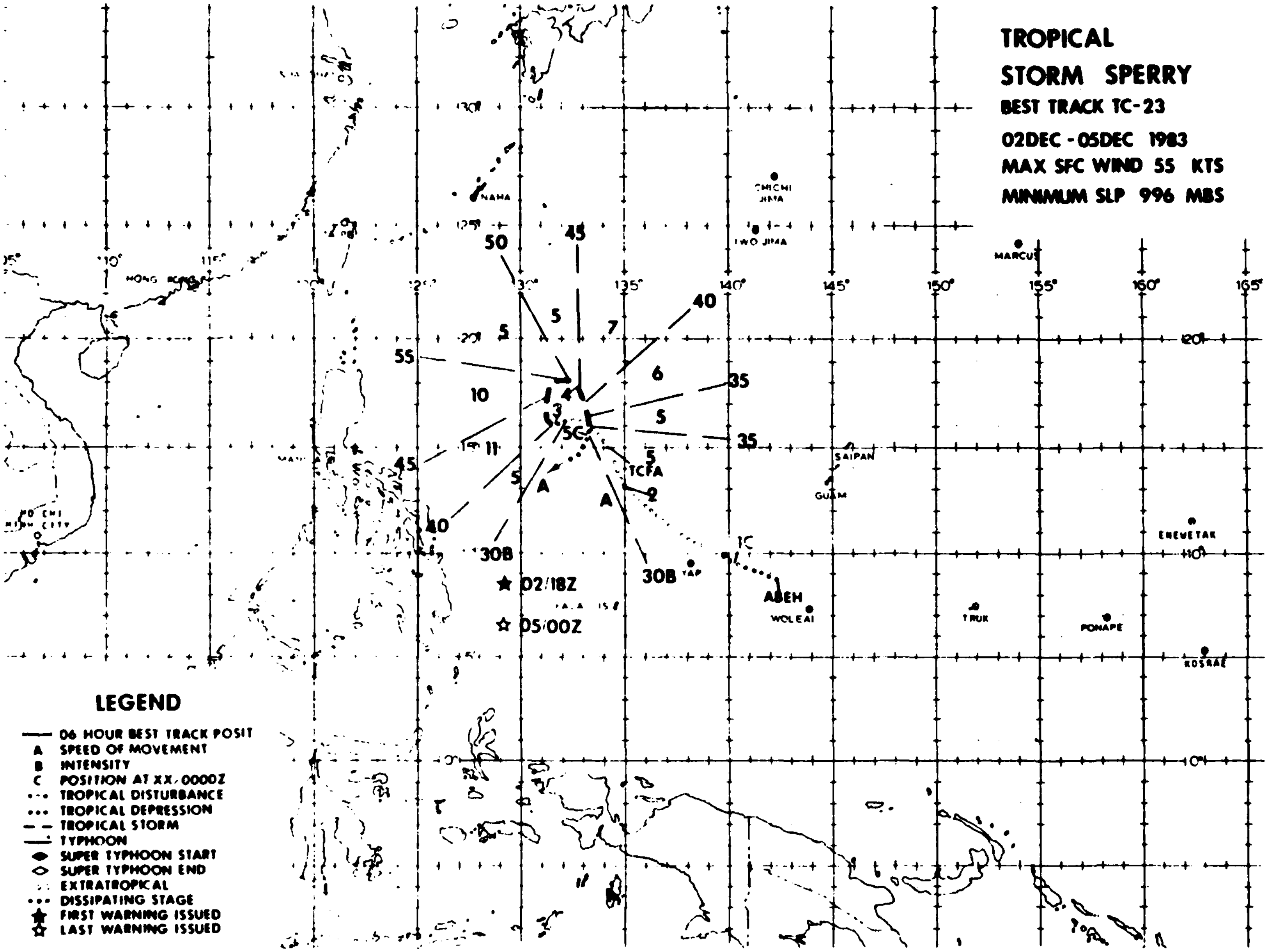
MINIMUM SLP 993 MBS

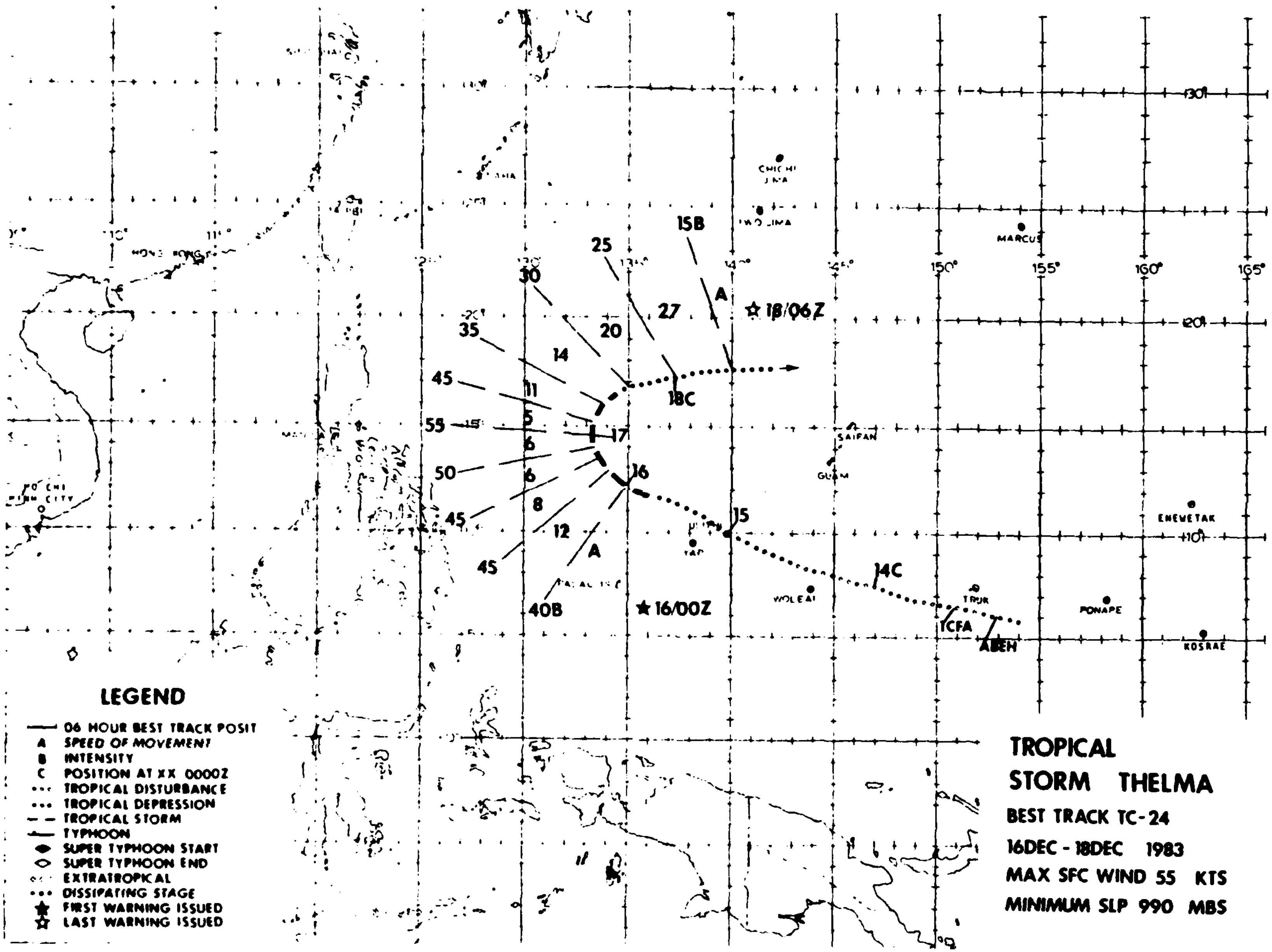


DTG	SPEED	INTENSITY
2300Z	3	30
2306Z	5	30
2312Z	7	30
2318Z	7	30
2400Z	5	20
2406Z	5	20

LEGEND

- 06 HOUR BEST TRACK POSIT
- A SPEED OF MOVEMENT
- B INTENSITY
- C POSITION AT XX/0000Z
- ••• TROPICAL DISTURBANCE
- ••• TROPICAL DEPRESSION
- — — TROPICAL STORM
- —— TYPHOON
- ◆ SUPER TYPHOON START
- ◇ SUPER TYPHOON END
- EXTRATROPICAL
- ••• DISSIPATING STAGE
- ★ FIRST WARNING ISSUED
- ☆ LAST WARNING ISSUED


TROPICAL
STORM SPERRY
BEST TRACK TC-23
02DEC - 05DEC 1983
MAX SFC WIND 55 KTS
MINIMUM SLP 996 MBS
LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
02/18Z
05/00Z
TCFA
30B
NAHA
CHICHI JIMA
IWO JIMA
MARCUS
SAIPAN
GUAM
YAP
WOLEAI
TRUK
PONAPE
ENEWETAK
KOSRAE
HONG KONG
HO CHI MINH CITY



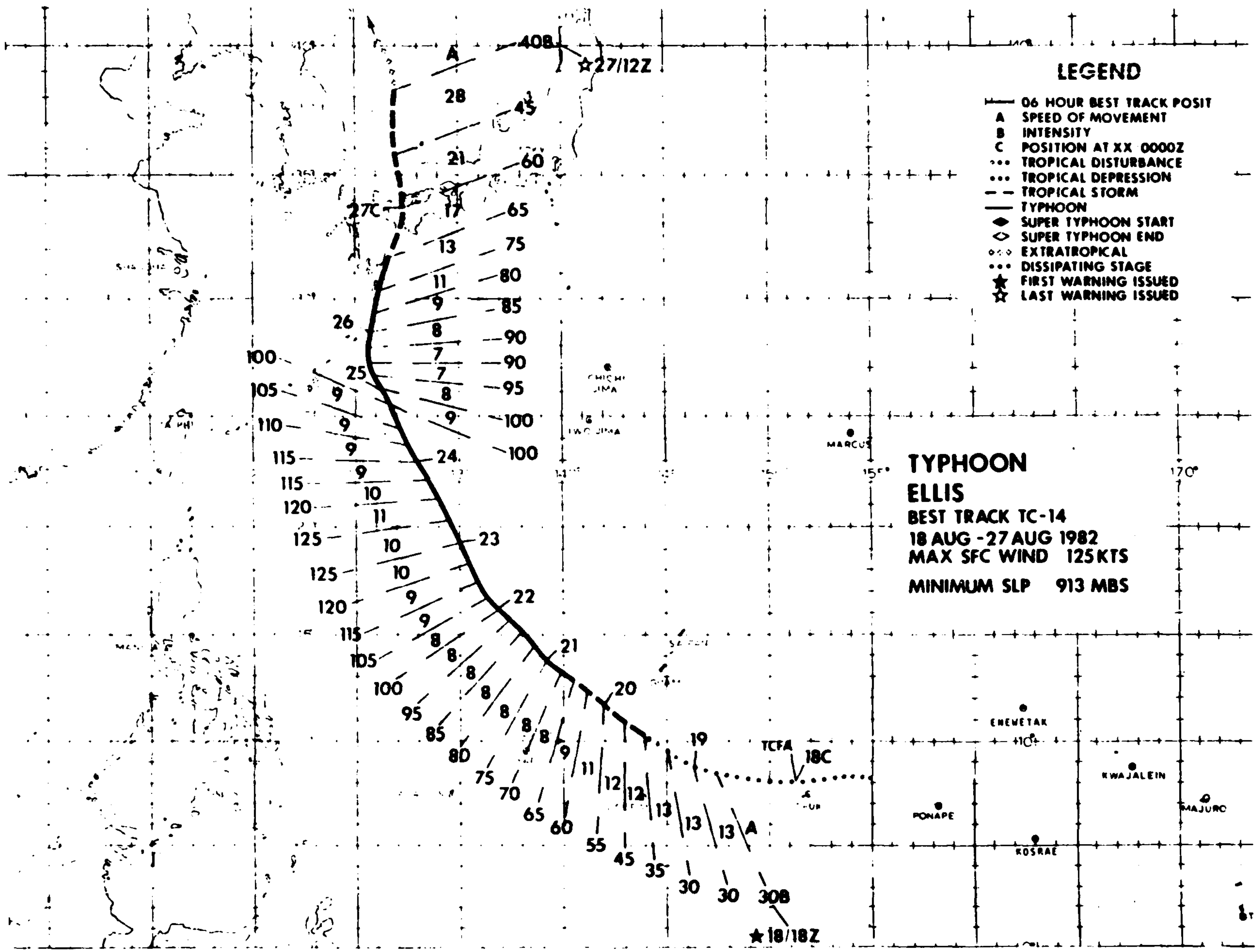
TROPICAL STORM THELMA

BEST TRACK TC-24

16DEC - 18DEC 1983

MAX SFC WIND 55 KTS

MINIMUM SLP 990 MBS



LEGEND
06 HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX 0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
TYPHOON
ELLIS
BEST TRACK TC-14
18 AUG - 27 AUG 1982
MAX SFC WIND 125 KTS
MINIMUM SLP 913 MBS
27/12Z
18/18Z
TCFA
18C
27C
MARCUS
ENEWETAK
KWAJALEIN
MAJURO
PONAPE
KOSRAE
170°

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